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Emigration of Juvenile Chinook Salmon in the Feather River, 1998-2001

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Summary

This report presents the results from the past three seasons (December 1998 through June 2001) of the Feather River Study chinook salmon emigration survey. The 2001 season was the fourth year the traps were fished throughout the entire emigration period.

Two rotary screw fish traps (RSTs) were used to assess the timing and general abundance of juvenile chinook salmon, steelhead and other fishes emigrating the Feather River. One RST (the Thermalito RST) was stationed at river mile (RM) 60.1, approximately one mile above the Thermalito Afterbay Outlet. The second RST (the Live Oak RST) was stationed at river mile 42, approximately one-third mile upstream of the Live Oak Recreation Area boat ramp.

Although chinook salmon and steelhead were the primary targets of trapping efforts, records were kept on all fish species caught. Twenty-six species were caught over the three seasons of trapping. Chinook salmon was the dominant species, comprising over 99% of the catch. Of the total salmon catch, 626,281 (38%) were caught at the Live Oak RST and 1,019,408 (62%) were caught at the Thermalito RST.

Of the salmon trapped at Thermalito and Live Oak, 96.6% and 81.4%, respectively, were less than 50 mm, demonstrating that most Feather River salmon emigrate well before smolting. Salmon ranged from 24 to 210 mm fork length. Salmon emigration was observed as soon as the traps were installed in November, typically peaked in February, and continued through June at very low levels.

Separate chinook emigration estimates were developed for the Low Flow Channel (LFC) and High Flow Channel (HFC). Over the three years, estimates ranged from 7.1 to 16.8 million fall-run-size fish in the LFC and 5.2 to 29 million for the HFC. Emigration estimates were also generated for spring-run-size fish. Application of the estimates for spring-run-size fish warrants caution.

Flow (cfs) and turbidity (secchi depth) were not shown to influence fall-run emigration timing or abundance before April 1. The timing of spawning the previous fall may play a large role in determining when juvenile salmon emigrate from the Feather River. After April 1, photoperiod and temperature may influence fry and smolt emigration behavior.

Based on adult escapement, average fecundity and the LFC emigration estimate the egg-to-fry survival rate for fall-run-size chinook juveniles in the LFC was 13.7% in 2001. The emigration index (per capita production) of juveniles in the LFC was 451**.**

A total of 1524 young-of-the-year steelhead were captured at Thermalito during the three-year period, but no yearlings (>150 mm fork length). Only 36 YOY and 4

yearlings were captured at Live Oak. In 2001, a nearly five-fold increase was seen in the number of steelhead fry captured at the Thermalito trap (compared to 2000).

Introduction

In 1996 DWR began to monitor salmon and steelhead in support of the Federal Energy Regulatory Commission (FERC) relicensing of the State Water Project's Oroville Facilities and to address issues raised by the Central Valley Project Improvement Act's (CVPIA) Anadromous Fish Restoration Program (USFWS 1997a). To this end, DWR initiated a study to identify the timing and magnitude of emigration of naturally produced salmon relative to different physical conditions and spawning population size. Although the main focus of the study is salmon and steelhead, other fish species were also recorded.

This study is the first on the emigration of salmonids and other fish species in the Feather River since the 1970's (Painter and others 1977). The salmon emigration study has the following objectives:

(1) Document general salmonid emigration attributes, such as timing, abundance and composition by species, race, and life stage.
(2) Investigate the influence of factors thought to initiate emigration, such as flow, turbidity, and water temperature.
(3) Develop annual indices of juvenile salmon production by relating information on spawning intensity and emigration. Use the indices to examine the effects of physical and biological factors on Feather River salmon production.

Salmon emigration is monitored primarily using rotary screw traps (RSTs). Two RSTs are installed, one at the lower end of each of the two study reaches, and operated for approximately seven months (mid-November through June). Two RSTs are necessary because flow is more strictly regulated in the Low Flow Channel than in the reach below Thermalito, and therefore emigration cues and species composition may be different for the two reaches.

The following report is a summary of salmon emigration between December 1998 and June 2001, representing three consecutive seasons of trapping efforts. Although the trapping season begins at the end of one calendar year and continues into the middle of the next (i.e. November through June), trapping years will be referenced by the spring season. For example, the 1998/1999 trapping period that ran from December 1998 through June 1999 will be referenced as the1999 season.

Methods

Study Area

The lower Feather River (Figure 1) is located within the Central Valley of California, draining an extensive area of the western slope of the Sierra Nevada. Lake Oroville, created by the completion of Oroville Dam in 1967, has a capacity of approximately 3.5 million acre-feet (maf) of water and provides flood control, water supply, power generation, and recreation. Flow in the lower Feather River below the reservoir is regulated through releases from Oroville Dam, Thermalito Diversion Dam, and the Thermalito Afterbay Outlet. Under normal operations, the majority of water released from Lake Oroville is diverted at Thermalito Diversion Dam into the Power Canal and Thermalito Forebay. Water released from the Forebay is used to generate power as it is discharged into Thermalito Afterbay. Water is returned to the Feather River through the Thermalito Afterbay Outlet, and then flows southward to the confluence with the Sacramento River at Verona. The remainder of the flow, typically 600-650 cubic feet per second (cfs), flows through the Low Flow Channel. The reach between Oroville Dam and the confluence with the Sacramento River is of low gradient.

The Feather River study area (Figure 2) is 25 river miles long and consists of the Low Flow Channel, which extends from the Fish Barrier Dam at river mile (RM) 67.25 to the Thermalito Outlet (RM 59), and the High Flow Channel, which extends from Thermalito Outlet to the confluence with Honcut Creek (RM 44). The Yuba River (RM 27.5) is 16.5 river miles further downstream from Honcut Creek. The study is focused on the upper 25 river miles (RM 42 to 67) of the lower river because it is (1) the portion of the river where most chinook salmon and steelhead spawn and initially rear, making them more affected by project operations and, (2) sampling in this reach provides the greatest opportunity to enumerate emigrating salmon and steelhead fry. River miles 0 to 42 are comprised mostly of flat-water habitat and fine substrates generally unsuitable for salmonid spawning.

The Fish Barrier Dam, just downstream of the Thermalito Diversion Dam, is the upper limit for upstream migrating fish. The base of the Fish Barrier Dam is where the fish ladder begins, guiding fish into Feather River Hatchery. The hatchery was built by DWR to mitigate for loss of chinook salmon and steelhead spawning and rearing habitat resulting from the construction of Oroville Dam and ancillary facilities.

Field Collection Methods

Two eight-foot Rotary Screw Traps (RST) are the main sampling devices used for the emigration survey. RSTs are sturdy, relatively easy to move within the stream, easy to operate and maintain, are able to capture fish without harm in fast-moving water and can be used to sample continuously. A RST operates in the following manner to capture fish: with the trapping cone lowered into flowing water, water strikes the baffles on the inside of the trapping cone, causing the cone to rotate. Fish enter the upstream end of the rotating trapping cone, become trapped inside the trapping cone, and are carried rearward into a live box.

One RST was initially placed at the downstream end of the Low Flow Channel at approximately RM 59.8, just upstream of the Thermalito Outlet (Figure 2). It was moved on 7 January 1999 to RM 60.1 to provide deeper water and more consistent velocities at the trap mouth. The second RST was placed in the High Flow Channel near the town of Live Oak (approximately RM 42) (Figure 2). Separate RSTs were needed because operation of the Oroville Complex results in two substantially different flow regimes: flow in the Low Flow Channel is strictly regulated (generally about 600-650 cfs), while the High Flow Channel is subject to flow fluctuations from 750 to 40,000+ cfs during emigration. Therefore, emigration cues and species composition may differ between the two reaches. The RST sites were selected based on the following criteria for RST installation, operation, and maintenance: (1) depth greater than six feet at minimum flow; (2) velocity greater than two feet per second at minimum flow; (3) suitable anchoring point(s); and (4) limited public access.

The RSTs were fished continuously for approximately seven months (mid-November through June), except for short periods at Live Oak when river conditions became unsafe due to high river flows. Both RSTs were serviced at least once a day and more often when a high debris load occurred. During servicing, trapped fish were removed from the live box, identified to species and counted. All fish were counted by hand if numbers permitted. When juvenile salmon were highly abundant, a simple volume displacement method was used to count them in increments of 1000. Fork length (to the nearest millimeter) was measured for up to 50 individuals of each species. The fish were then released back to the river, except for salmon retained for coded-wire tagging.

For five days in March 2000 (3/13/00-3/17/00), we conducted diel sampling to better understand salmon and steelhead emigration behavior. Both traps were checked several times, both day and night. The Live Oak trap was checked every four hours, while the Thermalito trap was checked every eight. All other trapping data were collected as usual.

All chinook salmon individuals were assigned to a race based on the length/date criterion set forth in the Sacramento River Daily Length Table (Greene, 1992). All live salmon and steelhead that were measured were also inspected for characters such as presence of parr marks, silvery appearance, and deciduous scales to determine life stage. A simple designation was used for each salmon measured:

P = clearly parr: a darkly pigmented fish with characteristic dark, oval-to round-shaped parr marks on its sides. (Note: for the 2000 and 2001 trapping seasons, the codes P, X and S were given subcategories 1-5 to further define life-stage

and to better coincide with other trapping operations).
(1) yolk sac fry/parr: yolk sac is clearly visible.
(2) fry: may have parr marks but yolk sac is not fully absorbed
(3) parr: clear parr marks and yolk sac is fully absorbed.

X = (4) intermediate: between parr and smolt. Usually has fading parr marks and some scale loss.

S = (5) smolt: highly faded or completely lacking parr marks, bright silver or nearly white color and heavy scale loss.

A salmon tagging station was set up at the Thermalito Afterbay Outlet to coded-wire tag (CWT) in-channel produced juvenile salmon. Juvenile salmon captured in the RSTs were transported to the tagging station and implanted with a CWT half-tag (Northwest Marine Technology, Inc., Washington). The tagged salmon were held overnight while a sub-sample was checked for tag shedding and survival. Tagged salmon were released immediately downstream of the Live Oak boat ramp.

Other measurements collected daily at each RST included: water clarity (secchi depth or turbidity), water temperature, the length of the sample period, average trapping cone revolutions per minute, and the total number of trapping cone revolutions during the sample period. Additionally, overall trap performance was evaluated by determining whether the trap was fishing was good, fair or poor during the trapping period. Simply put, a “good” code meant the trap was fishing normally, a “fair” code was assigned when the trap was spinning very slowly or was partially blocked with debris and “poor” code was assigned when the trap was not spinning. Daily mean river flow (cfs) for the Thermalito trap was obtained by adding the Thermalito Diversion Dam flow (CA Department of Water Resources gauge AO 5191) to the Feather River Fish Hatchery Outflow (CA Department of Water Resources gauge AO 5990). River flow for the Live Oak trap was obtained by adding the Thermalito trap flow to the Feather River Outlet-Thermalito Afterbay flow (CA Department of Water Resources gauge AO 5975).

Trap Efficiency and Emigration Estimate

Trap efficiency was evaluated using fish collected in the RSTs. Thirty-six evaluations (over the three year period) were conducted using salmon captured in their respective traps (i.e. salmon trapped at Live Oak were only used for Live Oak trap efficiency evaluations). Evaluations were performed between December 1 and April 15, the period when nearly all emigration occurred. For each evaluation, approximately 1000 marked fish were transported roughly two kilometers upstream of each RST. Fish were released in equal proportions along river right, center and left (i.e. if 999 fish were tagged, approximately 333 were released at river right, center and left). Because holding trials revealed insignificant losses of fish held for 24 hours after marking, fish were generally released within an hour of marking. However, only healthy fish (based on visual observations) were released. No consideration was given to time of release (i.e. time of day). Diel sampling revealed that nearly all salmon were captured at night and therefore time of release was unlikely to influence recapture rates. RST catch was monitored for recaptures for three to seven days after marked fish were released. Although nearly all recaptures occurred within the first three days of release, all traps were monitored for up to seven days based on previous observations that all recaptures occurred in that time-period. Mortality between the release point and the trap was assumed to be negligible.

All salmon were marked with Bismarck Brown dye at a concentration of 2.4 grams to 115 L of water for 30 minutes. Other marking methods were investigated (CWT fish, fin clipping, photonic tagging), but due to the large number of fish needed for efficiency evaluations, Bismarck Brown proved to be the most efficient and reliable option. Additionally, trap catch often exceeded more than 20,000 salmon (35-40 mm fork length) over a 24-hour sample period, making even sub-sampling the catch for individual marks impractical.

Trap efficiency was defined as the proportion of the total number of emigrants that were captured as they moved past the trap. The approximate estimate of trap efficiency (TE) for each sampling period is similar to that given by Roper and Scarnecchia (2000):

$$TE = \frac{\sum_{i=1}^{n} R_{ji}}{M_j}$$

Where R_{ji} is the number of recaptured fish from the j^{th} release group on the i^{th} day, and M_j is the number of marked fish released. This estimate of efficiency assumes that (1) all released fish continue downstream after release, (2) handling does not affect fish behavior, (3) mortality rates are zero, and (4) marked fish mix randomly with unmarked fish.

The average RST efficiency value at each trap over three seasons (1999, 2000 and 2001) was used to calculate an estimate of the number of fish emigrating from the Low Flow and High Flow Channels in 1999 (see Discussion). Efficiency values measured in 2000 and 2001 were only applied to data for the respective year. Although efficiency tests were performed separately each week, two adjoining weeks of efficiency values were averaged to calculate daily trap efficiency and daily emigration past each trap for the respective time-period. This was done to avoid bias associated with few recaptures (less than 7; Roper and Scarnecchia, 1999). Two efficiency tests performed at Live Oak did not meet this criterion and are therefore potentially biased. For weeks between 1 December and 15 April without efficiency tests, the average efficiency value for the year was used to calculate daily passage. Efficiency values were only applied to RST catch between 1 December and 15 April. For periods when the trap set for less than seven consecutive days, daily catch for the un-sampled period (*DCU*) was estimated by the following formula, where CS1 = total catch in the sample days before the un-sampled period; CS2 = the total catch after the un-sampled period; D_1 = the number of days in sample period one and D_2 = the number of days in sample period two.

$$DCU = \frac{\sum(C_{S1}) + \sum(C_{S2})}{D_1 + D_2}$$

Daily passage estimates (DPE) were not made for periods when the trap was set for less than seven consecutive days, so as to avoid making unreasonable inferences about longer un-sampled periods (Roper and Scarnecchia, 2000). Daily passage estimates and 95% confidence intervals were calculated by Chapman's (1951) modification of Seber's (1973) expression:

$$DPE = [(Mj + 1)(Cj + 1)/(Rj + 1)] - 1$$

Whereby *Mj* is the number of marked salmon released for the trap efficiency during time period j, Cj is the number of unmarked salmon captured in the trap during the time period j and Rj is the total number of recaptures during period j. Daily confidence intervals (95%) for the period are calculated as

$$C.I. = DPE + Z_{\alpha(2)}[(VarDPE)]^{1/2}$$

where

$$Var(DPE) = DPE^2(Cj - Rj)/[(Cj + 1)(Rj + 2)]$$

The annual emigration estimate (EE) was the sum of Daily Passage Estimates plus raw daily catch (DC) for periods without DPEs.

$$EE = \sum_{d=dec.1}^{Apr.15}(DPE) + \sum_{d=Apr.15}^{July1}(DC)$$

The resulting emigration estimate is inherently low for two reasons. First, it uses only raw catch before December 1 and after 15 April and in periods when the trap is fished for less than seven consecutive days. However, very few fish emigrate before 1 December or after 15 April. Second, the trap is not fished during high flows and debris loads (as in the year 2000 at Live Oak).

The emigration estimate for the river can then be used to calculate an emigration index (EI) using the spawning escapement estimate from the previous fall. The emigration index is a per-capita production estimate that may be used to compare production from year to year. The index is calculated by dividing the emigration estimate (EE) for the river by the estimated number of adult/grilse females (F) determined by the fall escapement survey.

$$EI = \frac{EE}{F}$$

Juvenile salmon survival rate (SR) for the Low Flow Channel is computed as follows

$$SR = \frac{EE}{SF \times 5522}$$

Where SF is the number of successfully spawned females in the Low Flow Channel, 5522 is the average fecundity of Feather River chinook salmon females (personal communication with Armando Quinones, California Department of Fish and Game) and EE is the total juvenile fall-run salmon emigration estimate for the Low Flow Channel.

Due to unequal sampling effort among years, trapping effort (in hours per month) and number of salmon captured per hour (CPH) is reported for each year. Effort calculations were only performed for days when trapping performance was good or fair.

Adult Escapement and Environmental Variables

Linear and quadratic regression methods were used to evaluate the relationship between adult escapement and juvenile emigration timing. Individual weeks of escapement survey estimates were paired with individual weeks of emigration estimates. By adding approximately 95 days to the beginning date of each escapement survey week (paired from week 2 to week 14), the matching emigration survey week was determined. For example, week four of the escapement survey was the week of 9/25/2000. By moving forward 95 days from 9/25/2000 (to account for the approximate time (7 days) it would take a female salmon to die after spawning and therefore show up in the carcass survey), the emigration survey week of 12/29 is selected as the expected emigration period. This (95 + 7 = 102 days) was selected as the time lag between egg deposition and capture at the traps based on expected hatching times from a simple thermal sum model (development time = 468.7/average temperature during incubation), previous studies (Kindopp, 1999) and Feather River Hatchery (FRH) data. FRH data demonstrates that it takes approximately 85-90 days for salmon eggs to develop into 35 mm fry. Although FRH eggs/alevins receive the same water (at the Thermalito Diversion Dam water is diverted into the FRH and down the LFC) as naturally spawned eggs, development in-river may take slightly longer due to slightly colder temperatures within the substrate. This lag period then allows approximately 10 days for naturally spawned alevins/sac fry to complete emergence and rear for a brief period before passing the Thermalito trap.

The effects of river flow and turbidity on emigration timing were examined with simple linear regression. Temperature was not investigated as a variable influencing emigration (above Live Oak) because in all years nearly all of the fall-run had already emigrated past the Live Oak trap before average daily temperature exceeded 60° F (15.6° C).

Results

RST Catch and Species Composition

Twenty-six species were caught during the three surveys, 12 native and 14 non-native (Tables 1, 2 and 3). This is similar to the number of species caught in the three previous years of trapping (DWR 1999a). Chinook salmon was the dominant species, comprising over 99% of the catch for all three years combined. Of the total catch, 1,019,408 (62%) were caught at the Thermalito RST and 626,681 (38%) were caught at the Live Oak RST (Table 4).

The large numbers of salmon resulted in a high proportion of native fish (nearly 100%) in the catch. Native non-salmonids were also prevalent; 77.5% of all non-salmonids were native (Tables 2 and 3). However, the proportion of native fish differed between the two traps: 80% of the fish captured at Thermalito were native species, while 72.5% of the fish captured at Live Oak were native.

Salmon Emigration

Salmon were caught in both RSTs as soon as they were deployed. Monthly salmon catch at each RST is reported in Table 4. The highest daily catch at Thermalito was 31,162 on 11 February 2001 (Figure 3); the highest daily catch at Live Oak was 28,990 on 2 February 1999 (Figure 4). Catch was highest in January, February and March of each year. Salmon catch declined rapidly at both traps starting in April each year (Figure 5; Table 4), with the two traps averaging only 0.85 % of the total catch for the months of April, May and June combined. In contrast, January, February and March averaged 91.3% and 96.9% of the total chinook catch at Live Oak and Thermalito, respectively.

Length frequency distributions of salmon differed slightly at Thermalito and Live Oak (Figure 6). While both traps were dominated by 35-38 mm fish, the Live Oak trap showed a second but smaller peak of fish between 50 and 85 mm.

Salmon size ranged from 20 to 114 mm FL at Thermalito and 28 to 220 mm at Live Oak. Weekly mean fork length ranged from 30 to 87 mm at Thermalito and 31 to 82 mm at Live Oak. Mean fork length at each RST changed little until late April, then steadily increased until the end of trapping (Figure 7).

Of the salmon trapped at Thermalito and Live Oak, 96.6% and 81% were less than 50 mm, respectively. While 98% percent of the salmon caught at Thermalito were categorized as parr, only 83% of the salmon caught at Live Oak fit the parr description.

Salmon of an intermediate life stage comprised 1.8% of the catch at Thermalito and 12.7% of the catch at Live Oak. Only 0.2% and 1.3% of the fish caught at Thermalito and Live Oak, respectively, were smolts.

Diel Sampling

Nearly all salmon and steelhead were captured between 1600 and 0900 (Figure 8). All steelhead at Live Oak and 81% of steelhead at Thermalito were caught between 0400 and 0800. Salmon, however, were most abundant between 1600 and 2400 hours. Figure 9 illustrates the movement of salmon past the Live Oak trap. Clearly, most salmon move at night, but smaller groups of fish also move during the day and at dusk. Salmon caught during the day were significantly larger than salmon caught at night (Figure 10: two sample t-test; $T = 12.17$, $p < 0.0001$).

Trap Efficiency and Emigration Estimates

Thirty-six efficiency evaluations were conducted during the three-year study period (Table 5). Only efficiency evaluations using Bismarck Brown dyed salmon were used to determine emigration estimates. Recapture rates in the Thermalito RST ranged from 1.0% to 4.6% and averaged 3.0% (1.25 SD) over the three-year period. The Live Oak RST efficiency ranged from 0% to 6.5% and averaged 1.9% (1.77 SD) over the same three-year period. Emigration estimates for fall-run and spring-run-size fish in 1999, 2000 and 2001 are presented in Table 6.

The emigration index could not be calculated for 1999 or 2000 because the adult escapement surveys were incomplete. The emigration index for 2001 (LFC only) is 451. The index means that for every adult female chinook salmon that spawned in the Low Flow Channel, 451 juvenile chinook salmon passed the screw trap at Thermalito in the winter and spring. This implies a survival of 13.7% from the time of egg deposition to capture at the Thermalito trap.

Influence of Flow on Trap Efficiency

Flow correlated well with trap efficiency at Live Oak ($r^2 = .75$, $p<0.04$). A strong correlation between river flow and trap efficiency would allow estimation of trap efficiency (and therefore fish passage) for periods when efficiency tests cannot be performed. However, the sixteen efficiency evaluations (pooled from 1999-2001) used in the analysis were conducted during flow releases between 1640 and 5470 cfs. The strength of the correlation is unknown at higher flows. For these reasons, flow was not used to estimate efficiency for days when efficiency tests were not performed.

Coded-wire Tagging of Naturally Spawned Salmon

A summary of DWR tagging efforts of naturally produced fall-run chinook salmon is presented in Table 7. The goal for future years is to repeat the 2001 effort. As tagged salmon return over the next several years, we will evaluate the return success of naturally produced fish compared to hatchery stock.

Spring-Run-Size Chinook

Figure 11 illustrates that most spring-run-sized fish caught at the traps are small. They are nearly identical in size to the fall-run emigrating at the same time, clearly illustrating the uncertainties of using the Daily Length Table alone as an indicator of race. Figure 12 suggests two periods of emigration of spring-run-size fish at Live Oak, but only one at Thermalito. One cohort of spring-run-sized fish apparently passes the Thermalito RST early, and this, or a separate cohort, emigrates past the Live Oak trap over a longer period.

Figures 12, 13 and 14 illustrate the emigration patterns and catch distribution for spring-run-sized fish. In all three years, the highest catch was in December. In 1999, spring-run were caught only in December at Thermalito (Figure 13; November was not sampled), but were caught December through May at Live Oak. In 2000 and 2001, the highest catch was also in December. However, spring-run were caught at both traps throughout most of the sampling period, with a steady decline from December to March—a typical fall-run emigration pattern. Another pulse of spring-run-sized fish then passed Live Oak in April and May, presumably after rearing in the river to a larger size.

Late-Fall-Size Chinook

Very few late-fall-run-size chinook were present in the Feather River. Immediately after emergence, late-fall-size chinook were captured at both RSTs (Figure 15). Catch at both traps peaked in April, then quickly dropped. Only in 1999 were a significant number of late-fall-size salmon trapped. That year the Live Oak RST caught more than twice as many late-fall chinook as Thermalito. Nearly all late-fall-size chinook were captured as fry (Figure 16).

Steelhead

Over the three years, a total of 1524 and 27 naturally produced YOY steelhead (<150 mm) were captured at Thermalito and Live Oak, respectively (Tables 1, 2 and 3). No naturally produced yearling steelhead have been caught at Thermalito since 1996. However, 4 yearling steelhead were caught at Live Oak over the last two seasons. Additionally, two wild and one hatchery adult steelhead were captured at the Thermalito RST between 23 May and 28 June, 1999.

Steelhead catch predominantly occurs in February and March at Thermalito, with much smaller catch in April, May and June (Figure 17). In 2000 and 2001 the average size was 25.5 (+/- 5.0 SD) mm at Thermalito and 88.9 mm (+/- 81.8 SD) at Live Oak. 2001 was the only year a significant number of steelhead were trapped, providing 81.8% of the total steelhead catch over the past three years. Of 1157 captured in 2001, 1143 (98.8%) were caught at Thermalito (Figure 18).

Influence of Flow, Temperature and Turbidity on Emigration

Except for one event (2500-8000 cfs from 17-22 February 1999), Low Flow Channel flows were approximately 600 cfs year round (Figure 19). High Flow Channel flows ranged from a low of 1059 cfs in April 2001 to a high of 25,000 cfs in February 1999 (Figure 19). There is no evidence of a relationship between flow and chinook catch at Thermalito or Live Oak (Table 8). Fry passage at Thermalito varies considerably through time, while flows remain nearly constant. Although flows fluctuate at Live Oak, salmon catch rarely responds accordingly (Figures 3 and 4).

Secchi depth (water clarity) was generally lower during winter than in the spring (Figures 20 and 21). Water was normally clearer in the Low Flow Channel than in the High Flow Channel (Table 9). It is typical for Low Flow Channel water clarity to remain high because flows are usually constant and low. High Flow Channel water clarity can be influenced by flow fluctuations, sediment load in the Afterbay and discharges from Honcut Creek and agricultural land adjacent to the river. The variability from year to year at each trap is low, illustrating the Feather River's perennial stability. Although at times secchi depth did show a significant relationship to chinook catch at Thermalito and Live Oak (Table 10), the relationship is very weak.

Temperature did not seem to influence emigration significantly, because the average temperature at both traps did not exceed 60^{0} F (15.6° C) until most salmon had already emigrated (Figure 22). Average daily water temperature ranged from 40 to 65.5 °F (4.4 to 18.6 °C) at the Thermalito RST and 41 to 74.5 °F (5 to 23.6 °C) at the Live Oak RST (Figures 22, 23 and 24). Water temperature was low during winter, then steadily increased from March to the end of the sampling period.

Effort

Effort was generally consistent at Thermalito in all months except June (Fig. 25). Effort was somewhat variable at Live Oak due to high flows and debris loading in the winter months (Fig. 26). Catch rates were generally greatest in January and February, although in March 1999, Live Oak catch rates exceeded 230 salmon per hour (Figure 26). Low effort in 2000 at Live Oak (<300 hours in February and March) undoubtedly caused an underestimate of the number of salmon emigrating through the High Flow Channel (Table 6).

Influence of Adult Spawning on Emigration

Linear regression analysis of spent females (predictor variable) on the timing of juvenile fall-run salmon emigrants from the LFC revealed a significant pattern (Figure 27, r^2 = .663, p = .001, Y = 438999 + 500.828X). However, quadratic regression revealed a better fit to the data (Figure 28, r2 = .808, p =.0026, Y = 743.449 + 1271.37X – 0.16377X^2).

Discussion

Catch Differences between Traps

In two of the three years (2000 and 2001) the Thermalito trap caught more salmon than the Live Oak trap. In 1999, the opposite was observed (Table 4). There is no satisfactory explanation for the reversal seen in 1999. An increase in the proportion of salmon spawning below Thermalito Outlet in 1998 might explain the difference, but accurate spawning escapement counts for fall 1998 are lacking. Other potential explanations for the shift in catch include change in trap location, (and thereby a change in trap performance) and year-to-year differences in migration cues (flow, turbidity, precipitation) between the different reaches. Because catch increased immediately after moving the Thermalito RST in 1999, it is highly unlikely that overall salmon catch at Thermalito was reduced as a result of a location change. Furthermore, trapping effort in 1999 was high and consistent at Thermalito and somewhat reduced at Live Oak, exactly the opposite of what would be expected from the catch data. Additionally, because catch does not appear to be significantly related to any of the aforementioned environmental variables, it is unlikely that a change in any one of them would have caused the massive change in catch between the two years.

Salmon Emigration Estimates and Trap Efficiency

The accuracy of the emigration estimate is affected by several factors. Among them is trap efficiency. In 1999, trap efficiency evaluations were conducted with fish marked with an adipose fin clip. This method proved unreliable and time consuming. This was confirmed by the rapid increase in efficiency values seen after switching to Bismarck Brown dye for efficiency evaluations. Consequently, it was felt that using three years of trap efficiency data (1999-2001 combined) for the 1999 emigration estimate for both traps would better estimate salmon passage. Only test methods using Bismarck Brown dyed fish were included in the analysis.

Another factor affecting emigration estimates is the lack of trapping during lengthy high flow conditions. A total of 19 days of emigration was missed in February and March of 2000 at Live Oak, possibly during the peak. There is no reliable method to estimate passage during such long periods of trap closure. Roper and Scarnecchia (1999) used regression analysis of flow and catch to predict passage when traps could not be fished, but only for shorter periods of time (a few days). High flows also prevented fishing the Live Oak trap in 1999, but the timing and duration of trap closure were unlikely to have severely compromised the estimate.

The 2001 emigration estimates and index are clearly the most reliable, for the following reasons: 1) consistent flows at Live Oak; 2) no breaks in data collection due to floods; 3) efficiency tests were performed over the bulk of the emigration period; 4) more efficiency tests were performed in 2001 (both traps combined) than in any other year.

Future efforts should be directed toward measurement of trap efficiency under varying flow conditions. Preliminary analysis indicates that flow may be responsible for the efficiency values observed at Live Oak ($r^2 = .75$, $p=0.04$). With more efficiency data over a larger flow range, a relationship could be developed to allow a better estimate of passage at the Live Oak RST based on flow alone (as in Demko et al, 1998).

Emigration Variables and Run Timing

The 1999, 2000 and 2001 Feather River salmon emigration timing was similar to 1998 (DWR 1999a). Spring-run size salmon were caught as soon as the RSTs were deployed, indicating that emigration had begun in early November. In 1996 RST catch (DWR 1999b) showed emigration as early as mid-November. It is likely that spring-run size salmon emigrate in November in most years.

Emigration of fall-run-size fish was similar among years. Nearly all (>95%) juvenile chinook emigrate from the Low Flow Channel within a few weeks after emergence. In all years, 97% or more juvenile salmon had already passed the Live Oak screw trap by 1 April, probably ruling out temperature as a major driving force for early emigration. Environmental variables such as flow and turbidity (when muted or stabilized) appear to have a very small role in salmon emigration in the Feather River. Even though flows, turbidity and temperature are usually stable throughout the emigration period, peaks in RST catch vary from late January to late March.

Although it appears that flow, turbidity and temperature have little effect on emigration, it is possible that the altered flow regime on the Feather River mutes these historical emigration signals. Snider and Titus (1995) found that the timing of both fry and fingerling emigration was substantially different from that before construction of Folsom Dam on the American River. Additionally, measuring emigration during larger flow events (>15,000 cfs) is nearly impossible due to high debris loads. This creates bias toward more easily measured factors. However, these factors (flow, temperature, water clarity) have not proven to be significant in stimulating emigration.

It is also possible that warmer water on the valley floor (as compared to historical spawning grounds at higher elevations) causes fry to develop and emerge sooner than the river is capable of supporting them. The result is immediate and massive emigration due to a lack of food base in the winter/early spring. Historically, salmon may have emerged a month later and exploited the spring and summer food web. Perhaps salmon emigrate soon after emergence because competition for food in the LFC is so great that fry must disperse downstream to find adequate rearing habitat. Unwin (1986) found that the initial mass migration of chinook fry in Glenariffe stream, New Zealand, was most likely a result of competition for rearing habitat. Healey (1991) reported that a large downstream movement of chinook fry immediately after emergence is typical of most populations. He further reports that “the downstream migration of stream- and ocean-type chinook fry, when spawning grounds are well upstream, is probably a dispersal mechanism that helps distribute fry among the suitable rearing habitats. “

Salmon might also emigrate early to avoid high temperatures on the Sacramento Valley floor in the spring and summer. A related hypothesis is that the introduction of warm-water predators, such as striped bass, has selected against late-spring emigration.

The history of emigration in the Feather River is poorly known. Sampling performed by Painter et al. (1977) between 1968 and 1973 provides little insight into the reasons for heavy early emigration of fry. Current benthic macroinvertebrate work, performed through a contract with California State University, Chico, will provide more information on the ability of the winter/spring food web to support juvenile salmon and steelhead.

Further complicating the detection of significant environmental variables on emigration timing is the influence of Honcut Creek on turbidity at the Live Oak trap. Honcut creek is a perennial tributary of the Feather River that is located approximately two miles upstream of the Live Oak trap site. Although discharge from the Thermalito Afterbay Outlet remains constant during even heavy rainfall, Honcut Creek responds rapidly. As the discharge increases in Honcut creek, water clarity rapidly declines. Only fish present in the two miles between Honcut Creek and the Live Oak trap are influenced by the increased flows and turbidity. All salmon rearing in the High Flow Channel above Honcut Creek are subsequently unaffected. Therefore, the data collected at the trap site (during freshets from Honcut Creek) only represents the Feather River for two miles immediately upstream. In other words, although water clarity and flow may be rapidly changing at the Live Oak trap site, many of the juveniles rearing in the High Flow Channel will not be affected by these changes. This may bias the characterization of physical cues at Live Oak, thus obscuring the connection between environmental change and chinook movement.

The end of emigration in all three years was similar to previous years (DWR 1999a). Painter and others (1977) found that, in 1968 through 1975, emigration could occur at least through the end of June in some years. Warner (1955) found that emigration ended around 1 June (in 1955). Although we believe that most salmon emigrate past Live Oak by 1 April, many remain. Snorkel surveys (DWR, unpublished data) have confirmed that as many as 500,000 juvenile salmon probably continue to rear in the Feather River throughout the spring. Furthermore, diver surveys find that as many as 20,000 juvenile salmon may continue to rear throughout the summer, mostly in the Low Flow Channel.

The rapid increase in fork-length at both traps between 23 March and the end of trapping implies that some chinook use the upper river as a nursery area in the spring.

Changing photoperiod and temperature together might create a migration cue for those fish. Roper and Scarnecchia (1999) found that photoperiod, or a correlated variable, was a migratory cue in the South Umpqua River, Oregon. However, the emigration peak in the South Umpqua is in summer, when long days might provide a strong cue. Furthermore, fish remaining in the river for several months grow larger and may have an advantage during emigration. They may be more adept at avoiding predators and finding food and be more physically prepared to smolt. However, fish emigrating in late spring may encounter a warmer river. Flain (in Unwin, 1986) reported that chinook juveniles that reared in fresh water for several months to a year comprised 76% of the adult angler catch in the Rakaia River, although they comprised only 5% of the juvenile population. It is possible that a similar pattern of prolonged stream residence is successful on the Feather River and other Central Valley streams. Salmon rearing into the spring and summer could emigrate in the fall when temperatures are more suitable for passing the lower river and estuary. Analysis of otoliths collected from naturally spawned adults in 2001 may provide some preliminary answers to this question.

This study confirmed the 1998 survey results (DWR 1999a), that the bulk of the emigrating salmon were pre-smolt. The percentage of salmon that was clearly smolt or intermediate between parr and smolt was less than 2% at Thermalito and 15% at Live Oak. Most were smaller than 50 mm fork length (97% at Thermalito and 81% at Live Oak). The high percentages of pre-smolt fish and fish smaller than 50 mm indicate that most salmon smolt downstream of Live Oak.

Regression Models and Emigration Timing

It is possible that emigration timing is more of an intrinsic trait than a response to changing environmental conditions. The main period of emigration appears to follow the corresponding period of spawning. Linear and quadratic regression revealed that peaks in emigration may correspond closely to peaks in escapement. Average fork length scarcely changes between mid- December and late March each year. This confirms that little growth occurs in this period, and suggests a very short rearing period.

The regression analysis relating escapement timing to emigration timing used in this report is merely an indication of a potential trend in the Feather River. Both the linear and quadratic models show strong and significant relationships between escapement and emigration. The true pattern may be a combination of the two.

The linear relationship is probably a reasonable estimation of the number of juveniles emigrating over a specified time-period. Roper and Scarnecchia (1999) used similar methods to relate the number of emigrating smolts to spawning adults from the previous fall. However, their relationship was based on pairing adult escapement in the fall with emigrating smolts in the spring over a four-year period. The results reported here are from only one year.

Because the data set is small, the linear regression is heavily influenced by three data points that lie outside the 95% confidence interval. These points likely correspond with issues of survival and superimposition. Theoretically, when escapement is high, survival to the traps should be relatively high. Egg mortality due to superimposition, however, can alter this relationship. If survival is exceptionally low for any one week when overall escapement is high (for example; 10/2-10/8, 7% survival, 5808 females), or vice versa, the relationship becomes less clear and less linear.

Furthermore, the time when a female superimposes another redd should affect the survival of the previously spawned eggs. If a female superimposes a redd soon after egg deposition, survival of the previously spawned eggs should decrease substantially. If the same female were to spawn a few weeks or a month later, survival should be greater, because eyed eggs can withstand disturbance better than their less developed counterparts (Burrows, 1949; Kindopp, 1999). As a result, large weekly peaks in spawning may show somewhat muted peaks in emigration, while moderate and small numbers of spawners may produce moderate or large peaks in emigration, due to a lack of superimposition. Therefore, the linear regression used in this analysis is heavily influenced by mortality caused during spawning. This could be from superimposition, spawning stress and even angling stress.

The quadratic regression model portrays a very different relationship, one that suggests a weekly carrying capacity for the LFC. According to this model, when more than 4000 females spawn in one week, the net output of juveniles declines, most likely due to mortality suffered from superimposition and stress-related spawning (i.e. under heavy spawning pressure, females may expel their eggs in an unproductive manner). However, the number of spent females exceeded 4000 fish in only two weeks of the year 2000 survey. Hypothetically, this means the river could support approximately 66,000 more females, assuming 50% female egg retention (50% of females sampled were unspent). This would imply approximately 40,000 additional males, making the total potential increase in adult salmon 106,000. This scenario does not include the potential loss of eggs due to the compounding effects of successive weeks of superimposition (i.e. 4000 spent females in 14 consecutive weeks instead of 4000 in just 2 consecutive weeks). However, it suggests that superimposition creates more space for spawners and allows higher total production of juvenile salmon, even though it reduces per capita production.

Superimposition is a natural phenomenon. The physical indicators of suitable spawning habitat are presumably pronounced at locations where females have already spawned. Therefore, these locations are probably more likely to be selected by subsequent females. Observations of trapping in Hatchery Ditch (a small secondary channel in the LFC) reveal that many steelhead eggs and alevins are dug up and washed downstream into fyke nets (DWR, unpublished data). Escapement of adult steelhead into Hatchery Ditch is very low (probably no more than 50 pair each year) compared to salmon escapement (roughly 1000-1500 spawning pairs each year). However, superimposition still occurs with regularity.

The level of superimposition in the LFC has presumably increased from natural levels since the completion of Oroville Dam. Both hatchery contributions and the reduction of habitat have likely contributed to its occurrence. However, at the same time, salmon escapement into the LFC has also been increasing (Sommer et al. 2001).

Spring-Run-Size Chinook

December appears to be a key month for emigration of spring-run-size fish. Just as for fall-run-size fish, the catch at Thermalito consists mostly of smaller fish, whereas the catch at Live Oak is dominated by small salmon early in the season, with much larger fish appearing in April and May.

The emigration estimate for spring-run-size fish must be viewed as approximate, for several reasons. First, the efficiency tests performed with fall-run-size salmon may not apply well to spring-run-size fish. Second, some spring-run-size fish may continue to rear in the river after the traps stop fishing. Third, and most important, separation of true spring-run from fall-run is difficult and uncertain. It is highly doubtful that the Daily Length Table (Greene, 1994) accurately distinguishes spring-run from fall-run in the Feather River. Valid use of the Length Table requires that spawning occur a few weeks earlier for spring-run, but no data exist to support this. Because the life history of the two putative runs in the Feather River are so similar (with no clear separation of spawning time), there is no way to accurately separate the two in the field.

The timing of emigration for spring-run-size juveniles is as unclear as the timing of spawning, since the former depends on the latter. Painter et al. (1977) used fyke nets to capture juvenile salmon fry between 1968 and 1973 at Live Oak. Although Painter et al. (1977) did not sample in November, they found very few juvenile salmon in December in each of the six years studied. DWR has sampled most of the emigration period (November/December-June) since 1996, and has captured salmon in November and December, which were called spring-run, based on the Daily Length Table.

It is possible that salmon in the study area rear to a size that makes them difficult to catch in screw traps. The Live Oak screw trap was ineffective at catching larger fish at low flows (1000-1500 cfs). For instance, flows dropped in early April 2001 from 1700 cfs to 1000 cfs. After this flow reduction the Live Oak trap nearly ceased fishing. After the trap was moved upstream a few hundred meters, it caught many salmon in the 60 and 70 mm range. If the trap had not been moved, there would have been no indication that fish of this size were on the move.

It is possible that fish of similar size were also passing the Thermalito trap. Due to physical constraints of the river, the Thermalito trap cannot be positioned to capture larger salmon on a regular basis. Therefore, capture of fish in the size range of sub-yearling or age-1 spring-run would be unlikely. Furthermore, trapping operations generally cease around 1 July, preventing capture of any summer emigrants. However, in 1999 both the Live Oak and Thermalito traps fished from July through October and caught 9 salmon, 8 at Thermalito. It is unknown whether this indicates the scarcity of salmon in summer or simple trap avoidance by larger fish. Both traps were generally spinning at 2-3 revolutions per minute, an indication of adequate trap performance.

Late-Fall-Size Chinook

Catches at both Live Oak and Thermalito suggest little production of late-fall-size chinook in the Feather River. Most late-fall-size chinook appear to emigrate soon after emergence. Essentially all late-fall-size salmon that were captured passed the traps within a month of emergence. This implies an emigration pattern similar to fall-run-size fish. However, diver surveys (DWR, unpublished data) indicate that many late-fall-size chinook rear in the Feather River well into the summer. Patterns of occurrence of late-fall-size fish are subject to the same caution as for spring-run-size fish. Their identification is based on the Daily Length Table, which provides no clear separation from fall-run-size fish.

More than twice as many late-fall-run-size were caught at Live Oak (chiefly in 1999) as at Thermalito. This suggests that more of these fish may have spawned in the reach below Thermalito. If fish spawned above and below Thermalito in equal numbers, similar number should be caught at both traps (assuming similar trap efficiency of late fall-run-sizes). The small number of late-fall-size juveniles captured in all years prohibits any firm conclusions about emigration patterns. The information does, however, suggest that few late-fall chinook spawn in the Feather River.

Steelhead

The presence of a few steelhead fry/parr in 1999 indicates at least a modest number of natural spawners in the winter of 1998. The 2000 catch was slightly larger, although still modest. In 2001, however, RST catch of steelhead fry increased five-fold from 2000. Thus, the three years saw a steady and marked increase in overall production (Tables 1, 2 and 3).

Very few yearling steelhead were caught during the study. This is probably attributable to three factors: 1) the scarcity of adults; 2) the ability of the larger fish to avoid capture; and 3) their lack of movement. Unlike most emigrating salmon, few juvenile steelhead appear to emigrate the Feather River immediately after emergence, when they are susceptible to capture. Nearly all steelhead captured are newly emerged (approximately 25 mm). Emigration typically peaks in March and continues into April in most years. Steelhead that are still in the river in April may set up a “home-range” and rear until they reach or surpass a size at which screw traps cannot catch them. Dive surveys confirm that even 60 mm salmon and steelhead can avoid the RSTs under some conditions of location and water velocity, making it difficult to gather information on steelhead emigration patterns (DWR, unpublished data). It further supports the need for other methods (diver surveys and beach seining) to understand the basic life history of fry, juvenile and adult steelhead in the Feather River.

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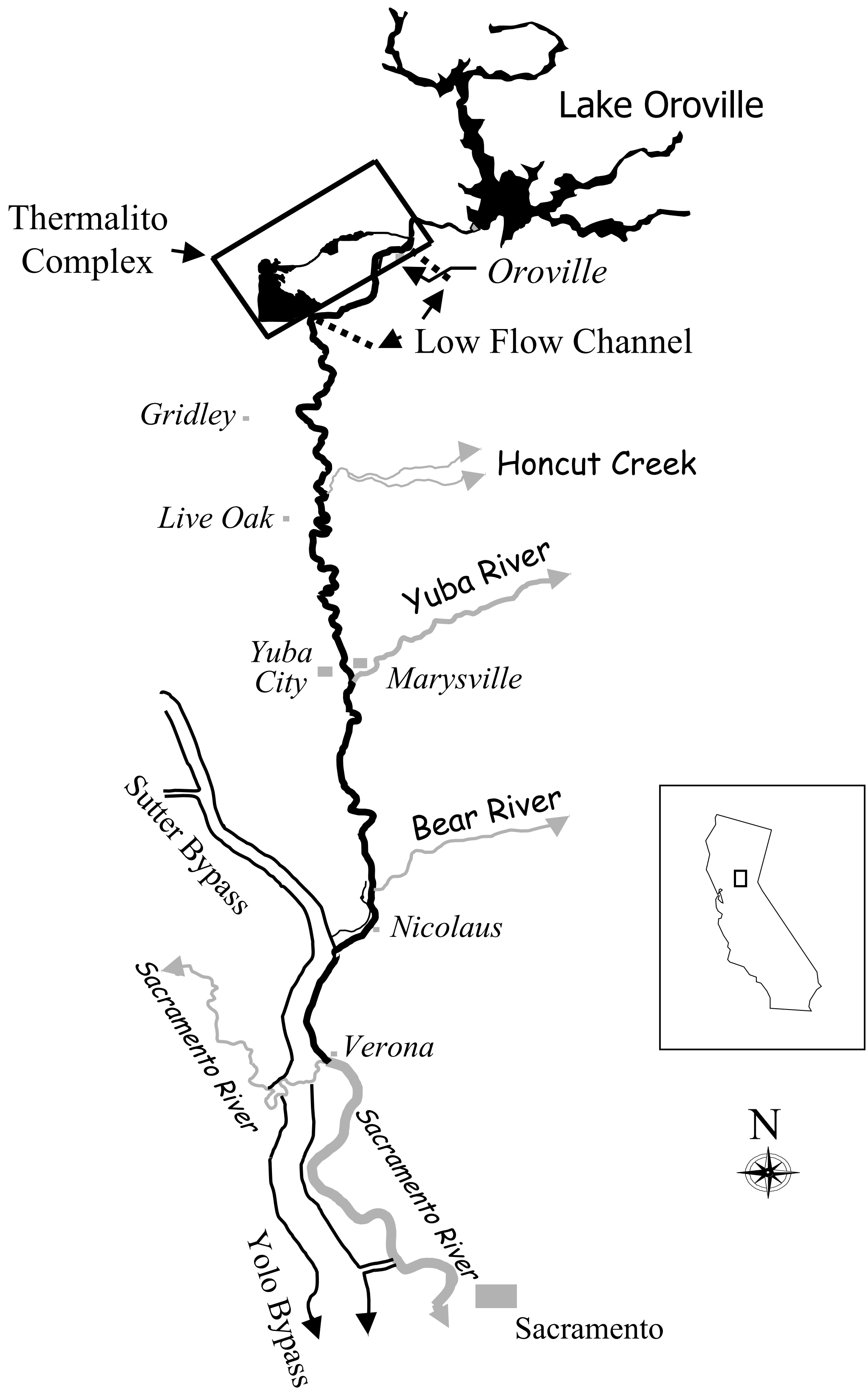


Figure 1: Lower Feather River and associated tributaries between Oroville Dam and the confluence with the Sacramento River.

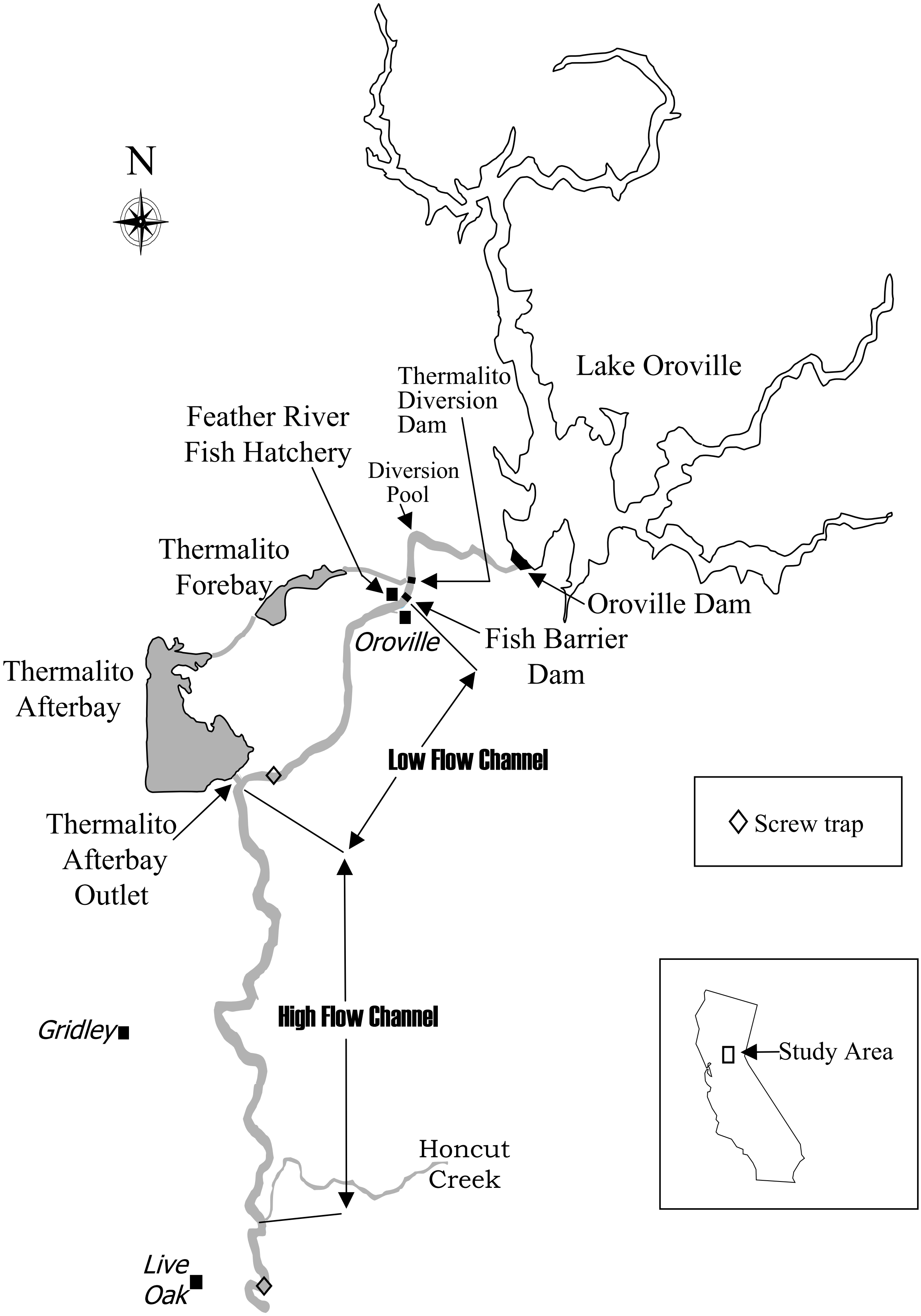


Figure 2: Feather River Study Area

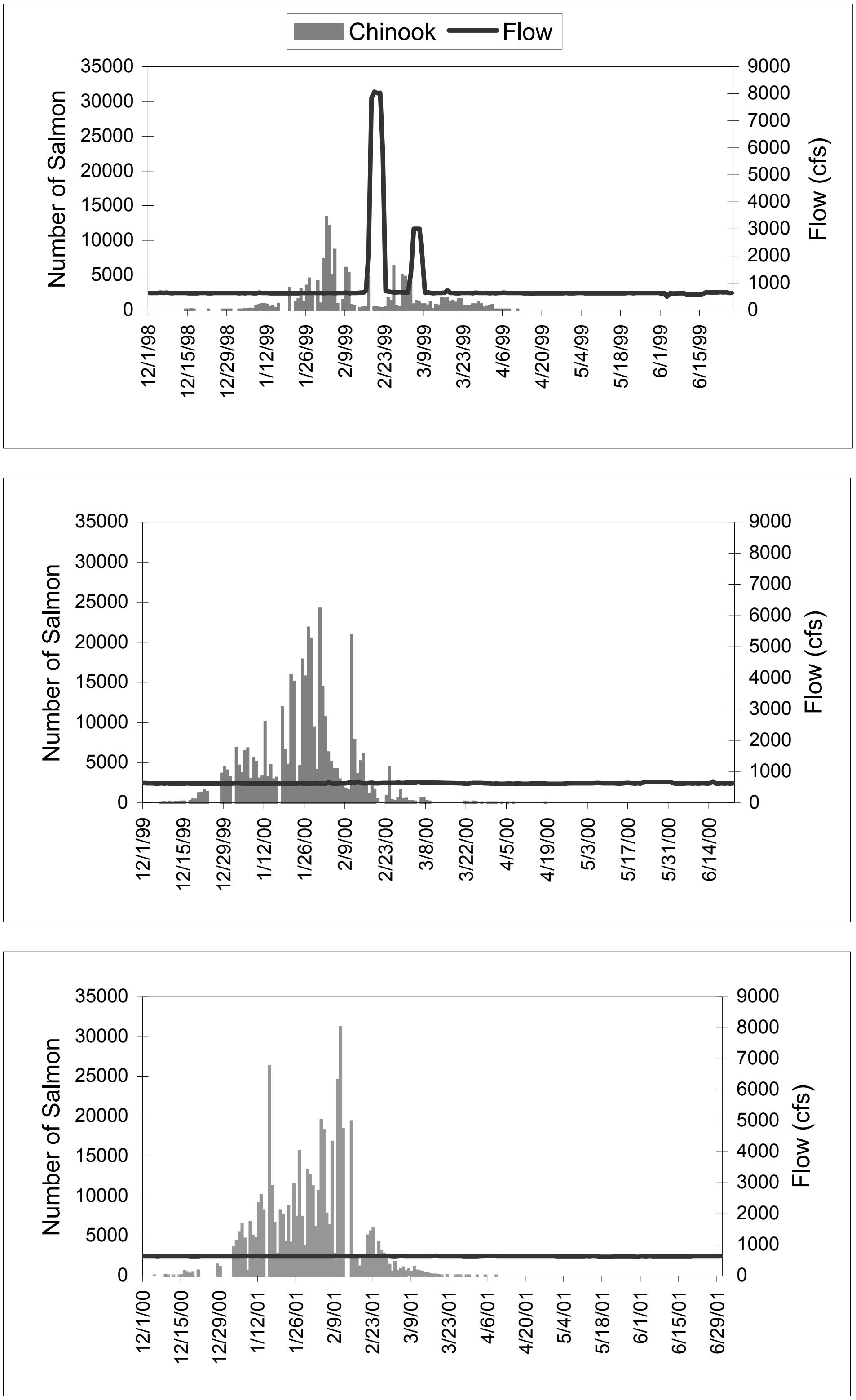


Figure 3. Daily catch distribution and flow associated with catch of fall-run size chinook at the Thermalito RST during all three years of trapping.

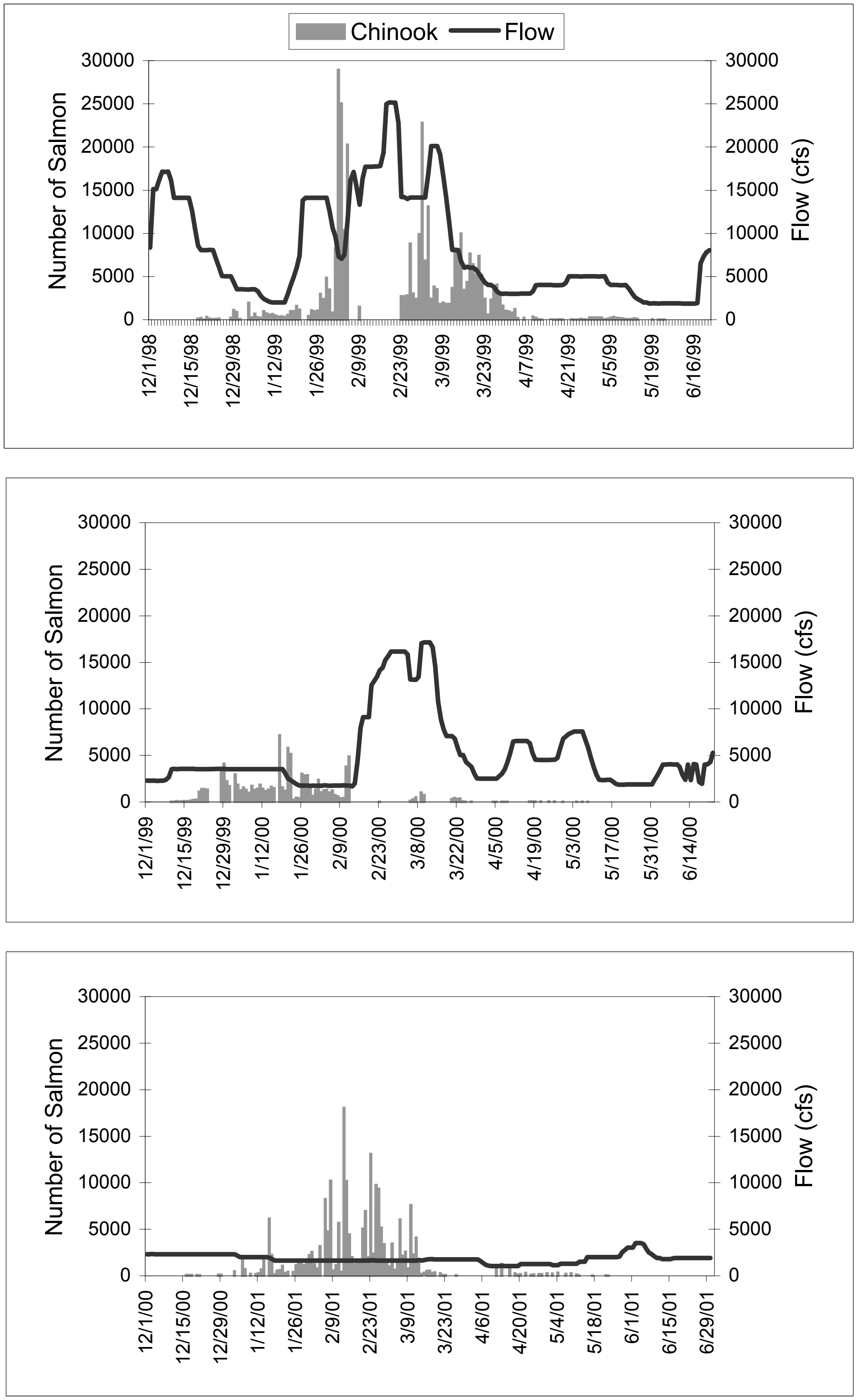


Figure 4. Daily catch distribution and flow associated with catch of fall-run size chinook at the Live Oak RST during all three years of trapping.

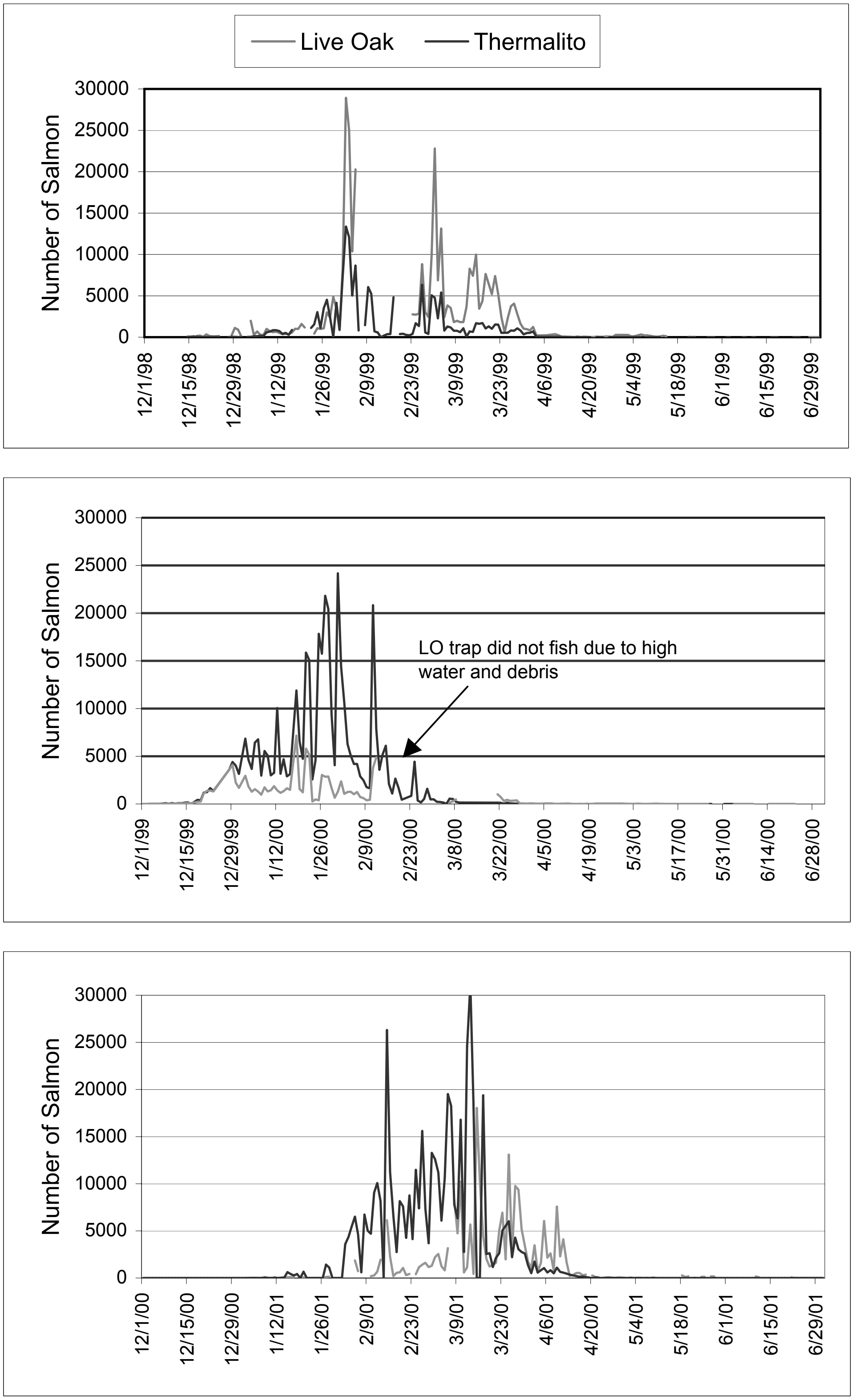


Figure 5. Daily catch distribution of fall-run size chinook caught at both RSTs during all three years of trapping.

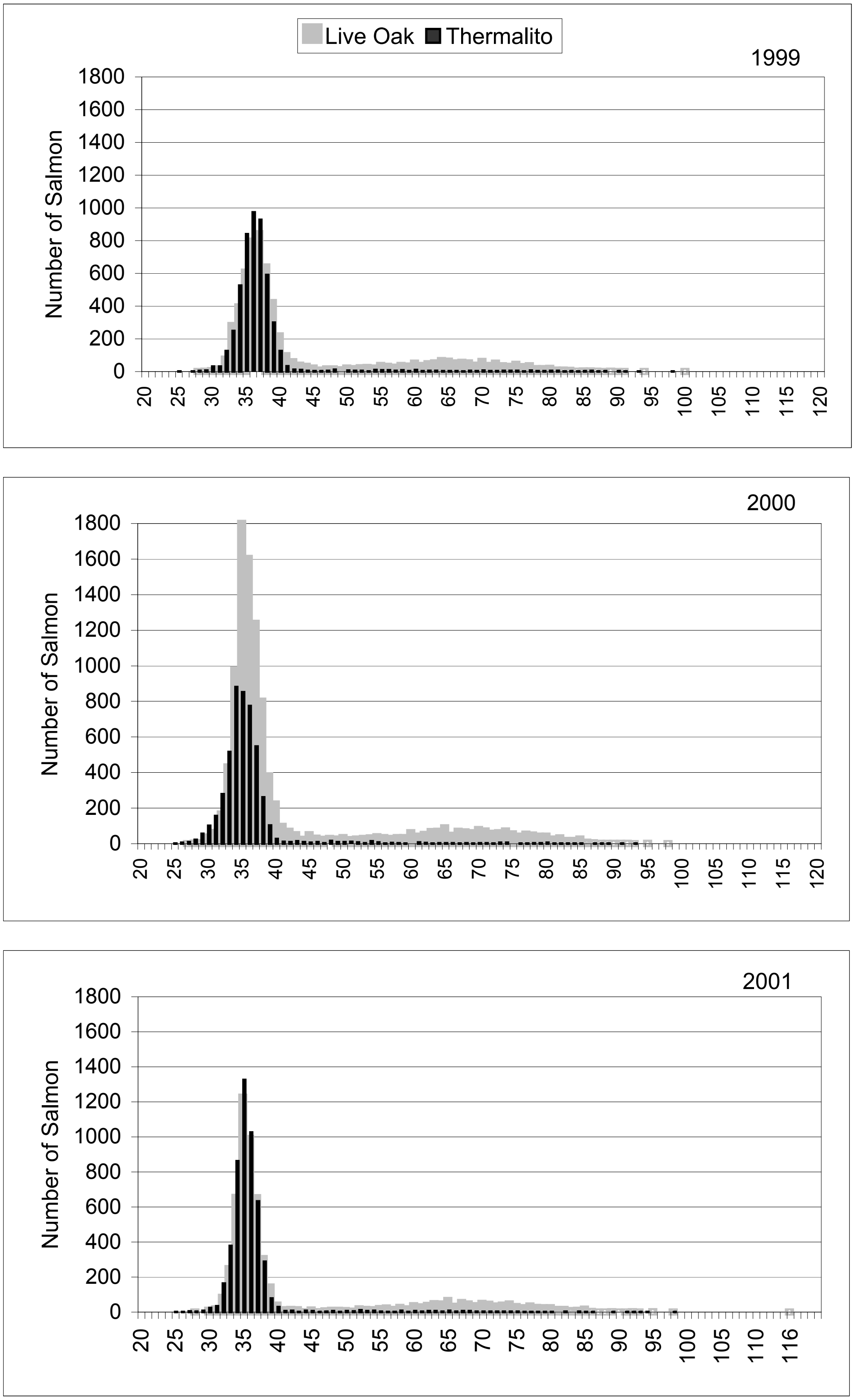
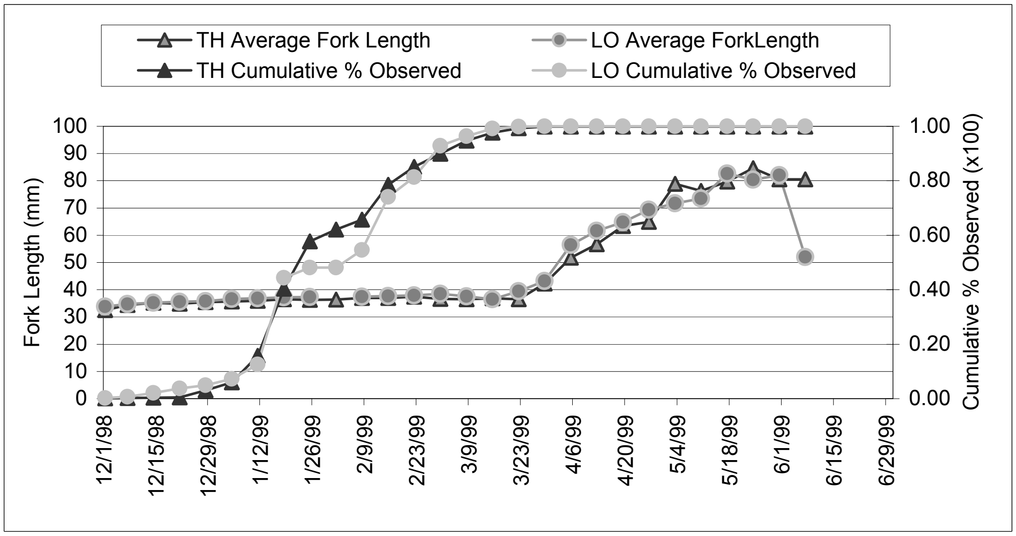
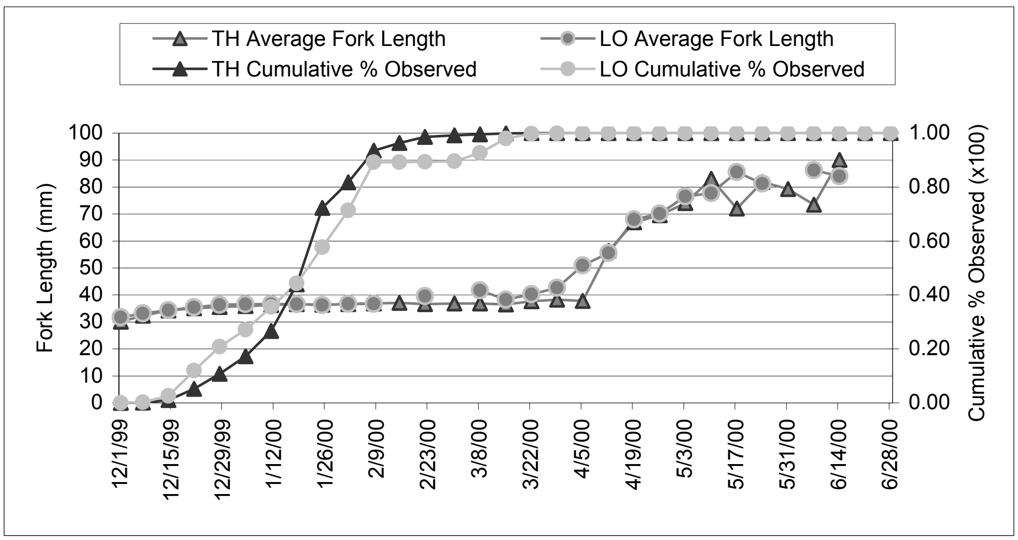


Figure 6. Length frequency distribution of fall-run size chinook at Thermalito and Live Oak during all three years of trapping.





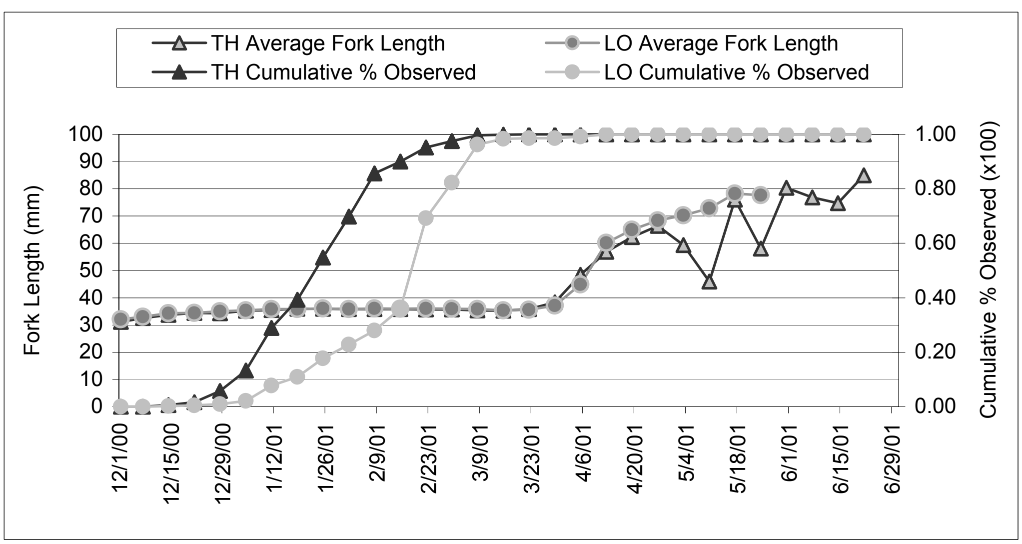
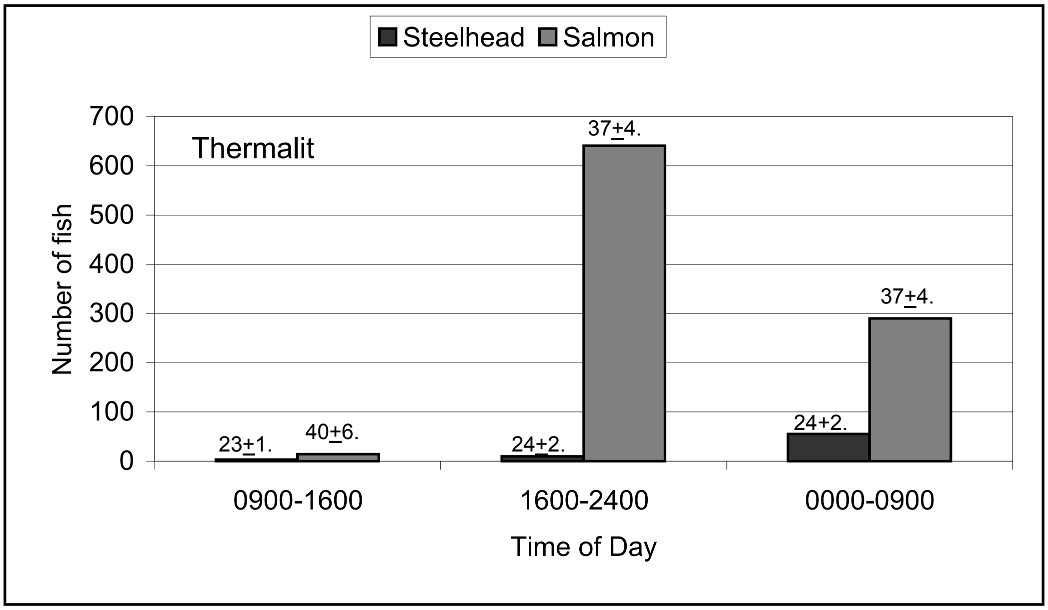


Figure 7. Average weekly fork length and cumulative percent observed of fall-run size chinook salmon at Live Oak (LO) and Thermalito (TH) during all three years of trapping.



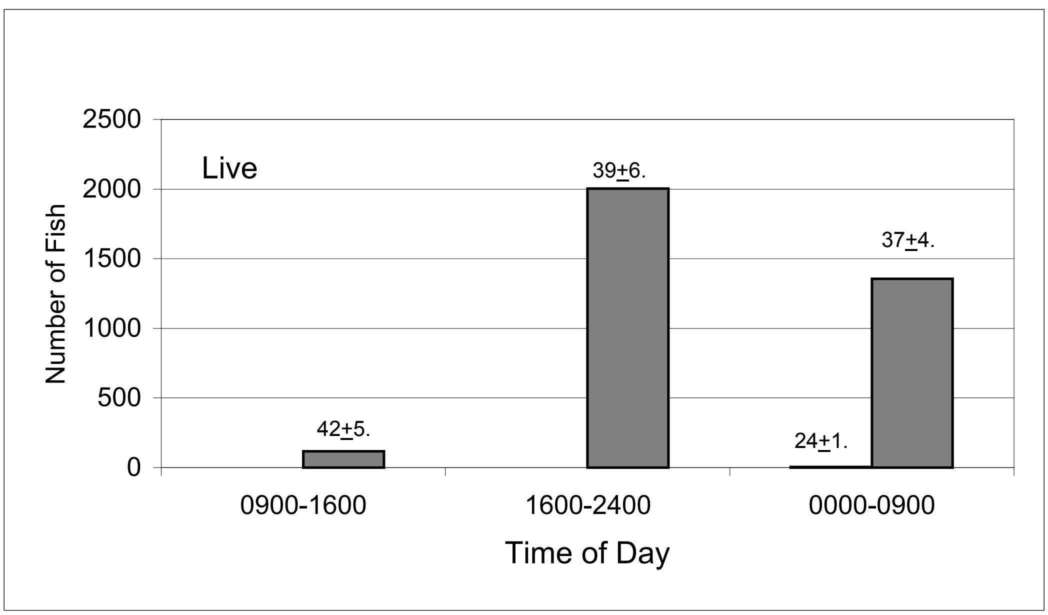


Figure 8. Catch of steelhead and salmon at the Live Oak and Thermalito screw traps during continuous diel sampling. Mean fork length ± one standard deviation are provided above each bar.

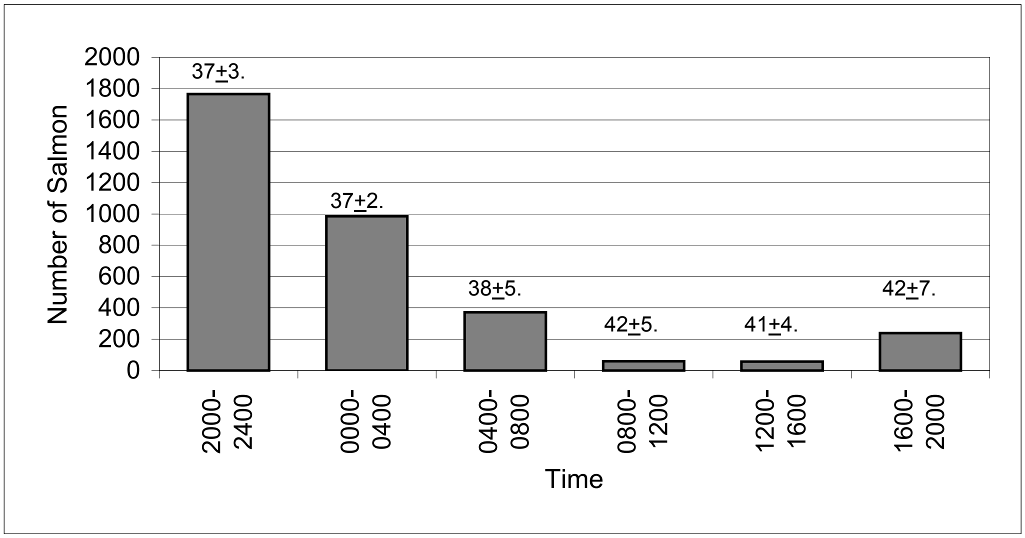


Figure 9. Catch of fall-run size size size size chinook salmon at Live Oak during continuous diel sampling at Live Oak (3/13-3/17/00). Mean fork length + one standard deviation are provided above each bar.

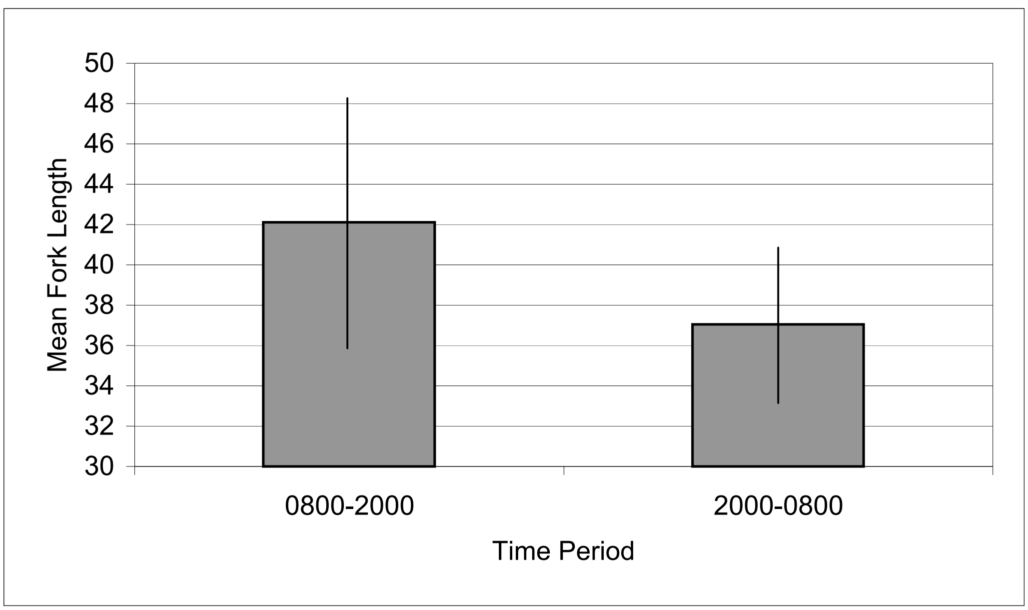


Figure 10. Mean fork length of fall-run size chinook salmon trapped at Live Oak during continuous diel sampling (3/13-3/17/00). Gray bars indicate mean values, vertical lines indicate the mean + one standard deviation. Means are significantly different (two sample t-test; T = 12.17, p < 0.0000).

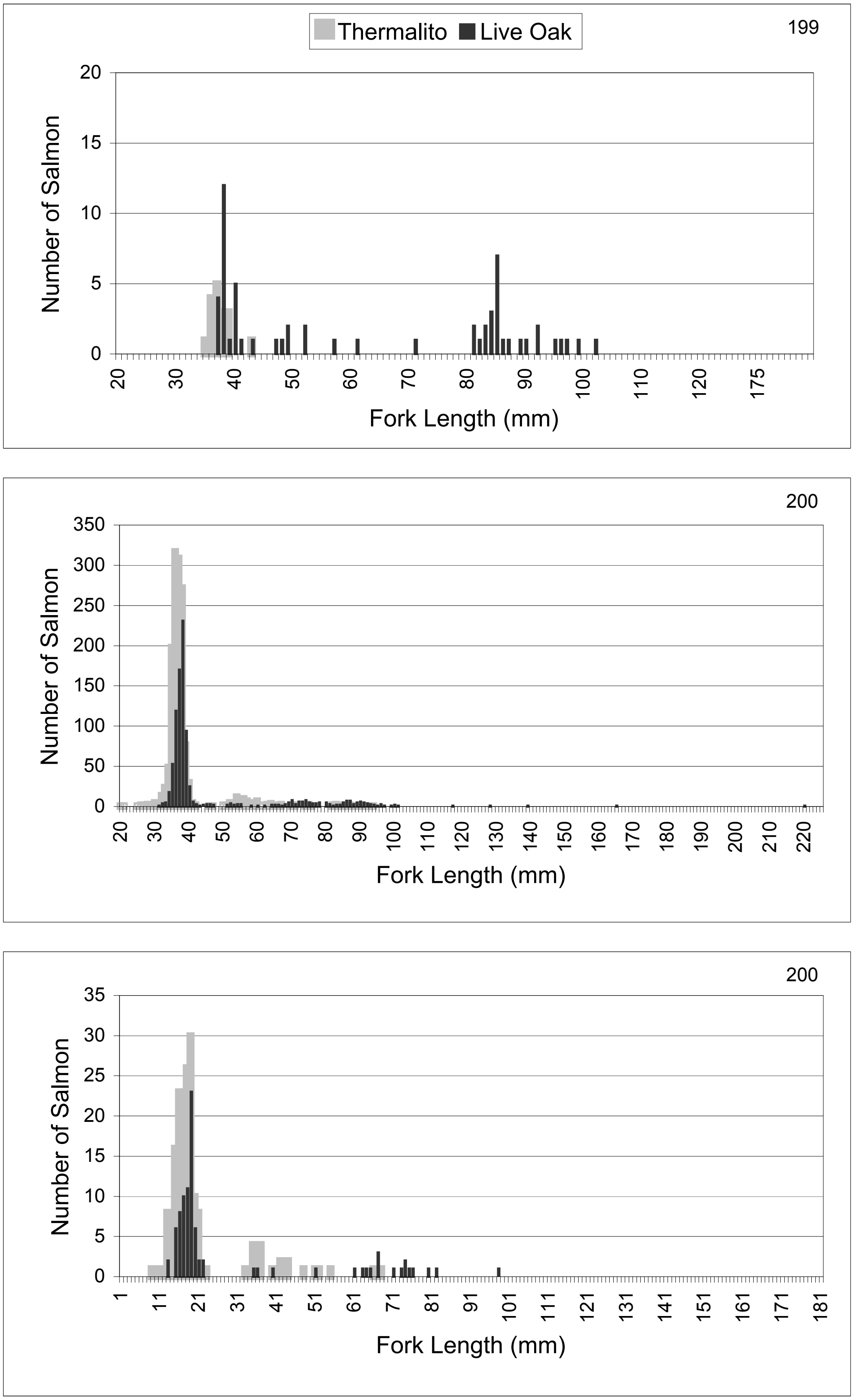


Figure 11. Length frequency distribution of spring-run size chinook captured at Thermalito and Live Oak during all three years of trapping. Note the y-axis scale changes.

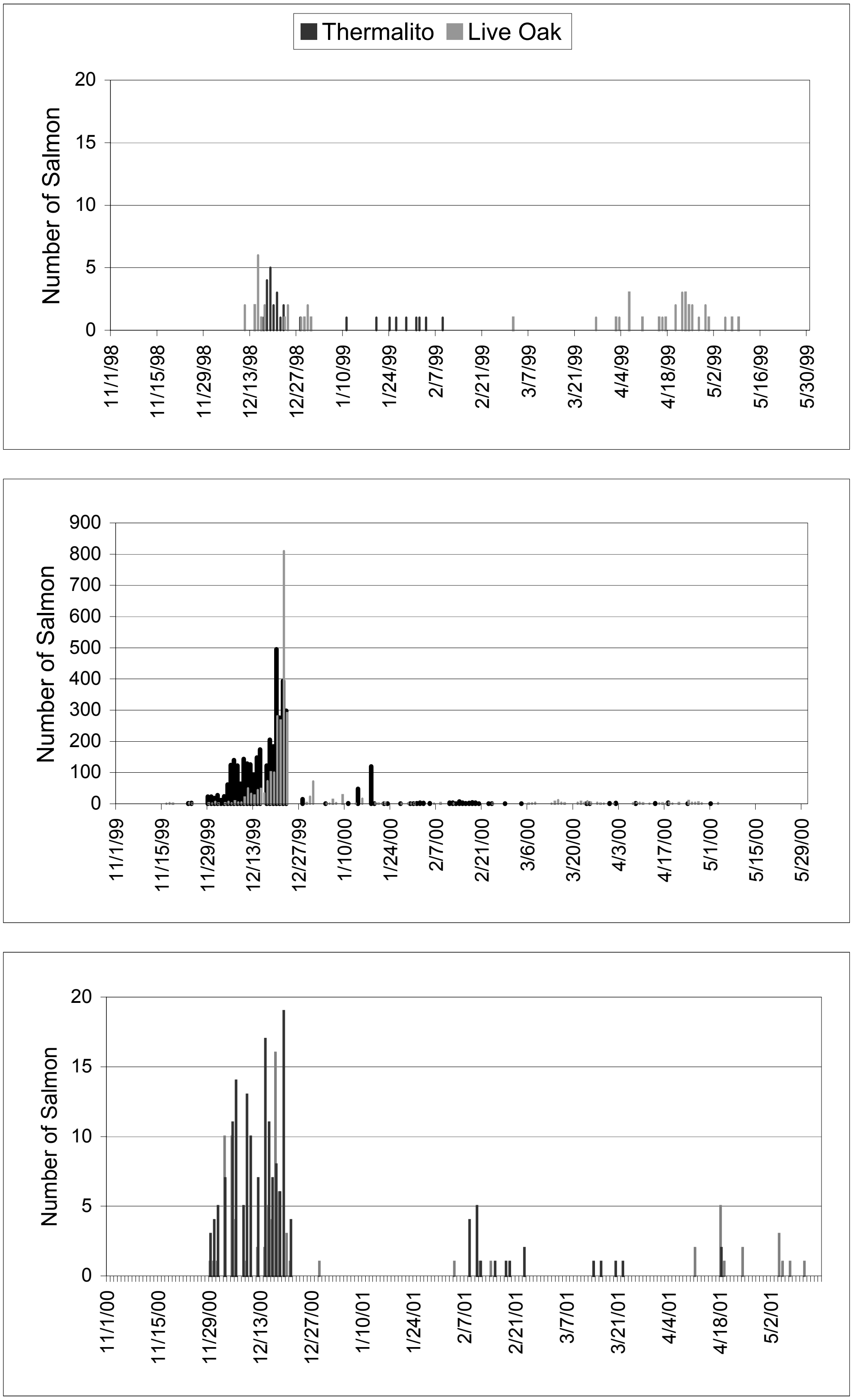


Figure 12. Catch distribution of spring-run size salmon (as designated by the Daily Length Table) at Thermalito and Live Oak during all three years of trapping. Note the y-axis scale change for the year 2000.

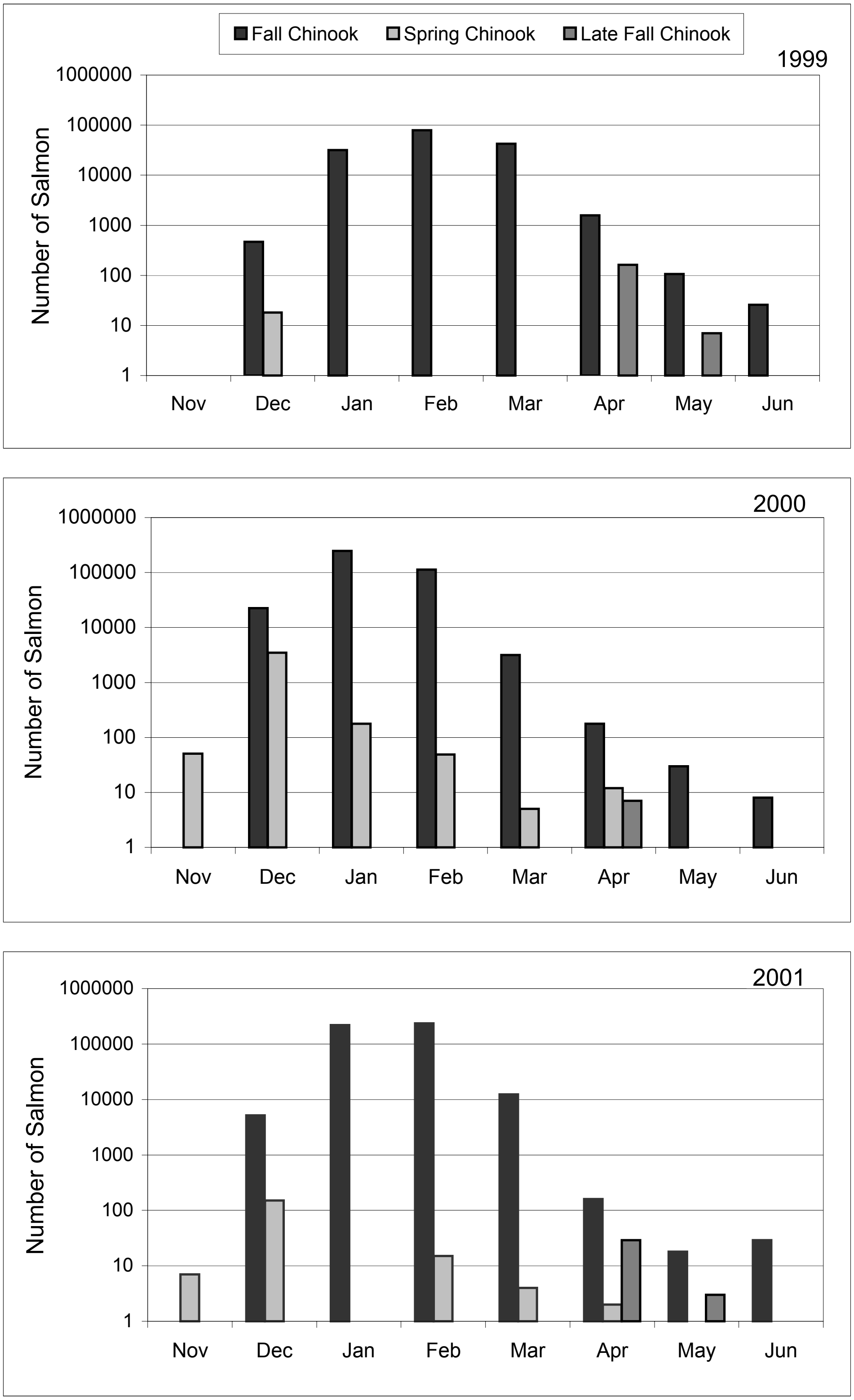


Figure 13. Catch distribution of three races of chinook salmon captured at the Thermalito RST during all three years of trapping. Note logarithmic scale. No data was collected in November, 1998.

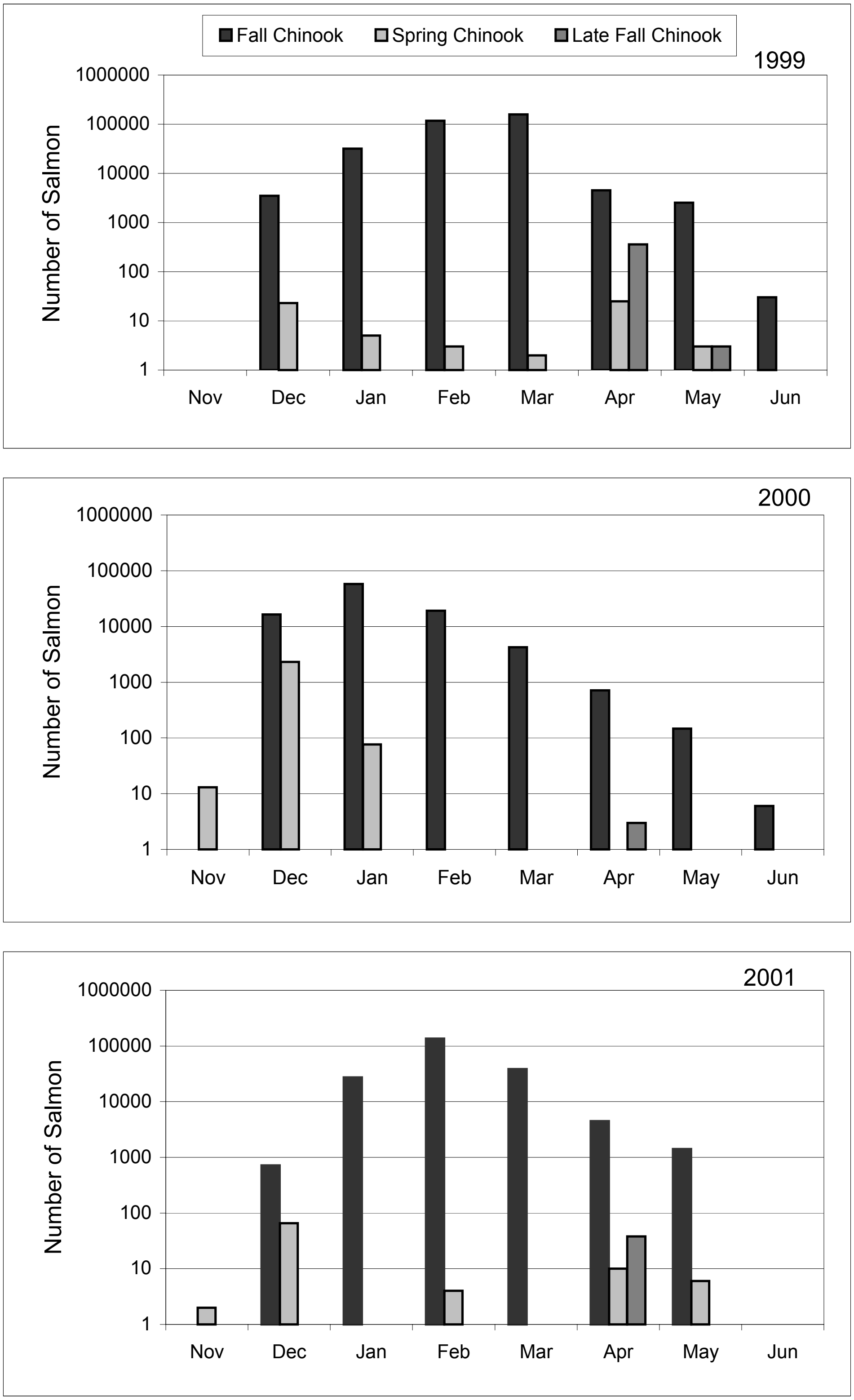
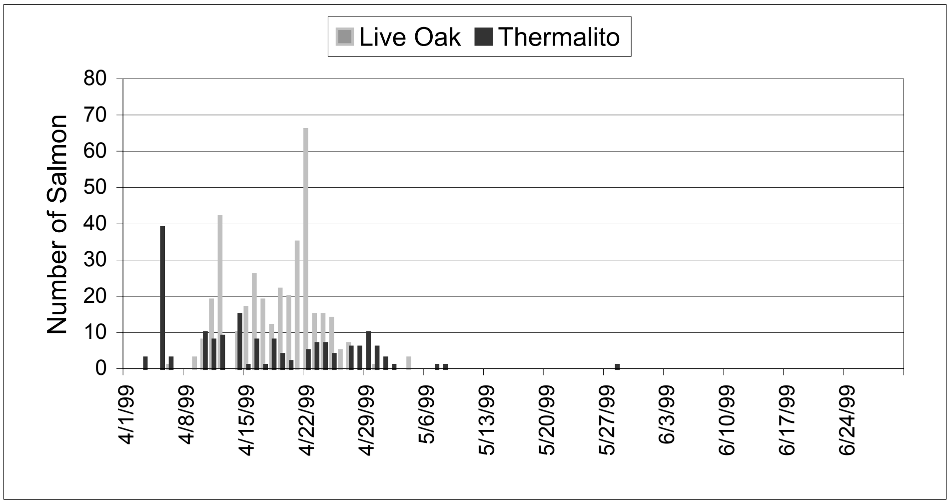
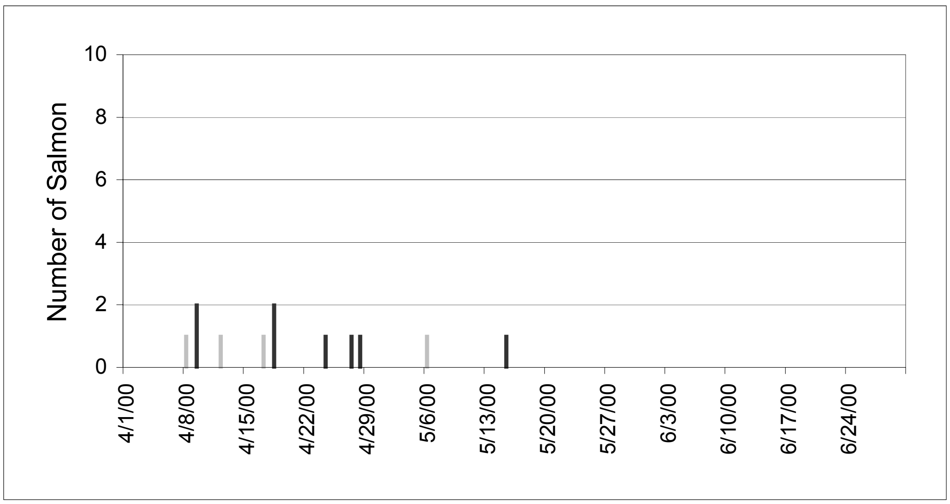


Figure 14. Catch distribution of three races of chinook salmon captured at the Live Oak RST during all three years of trapping. Note logarithmic scale. No data was collected in November, 1998.





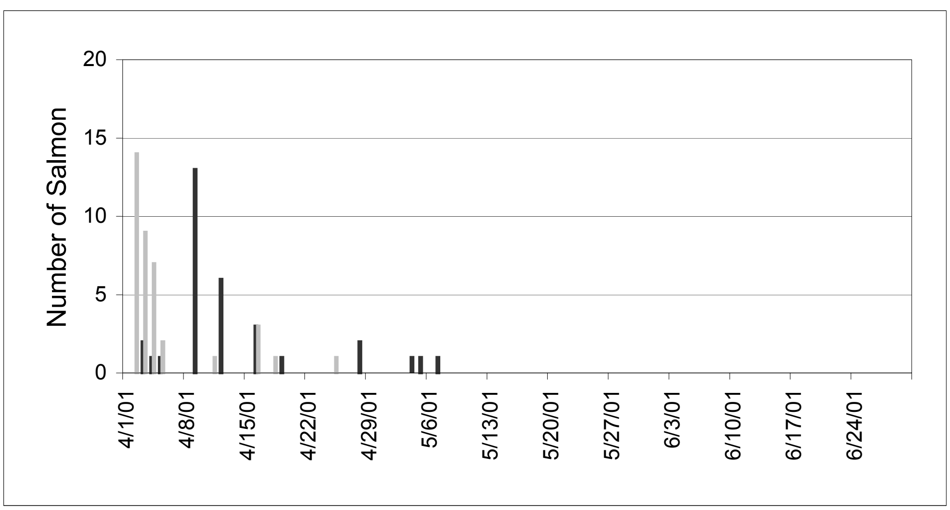


Figure 15. Catch distribution of late-fall size chinook at Live Oak and Thermalito during all three years of trapping. Note the y-axis scale changes.

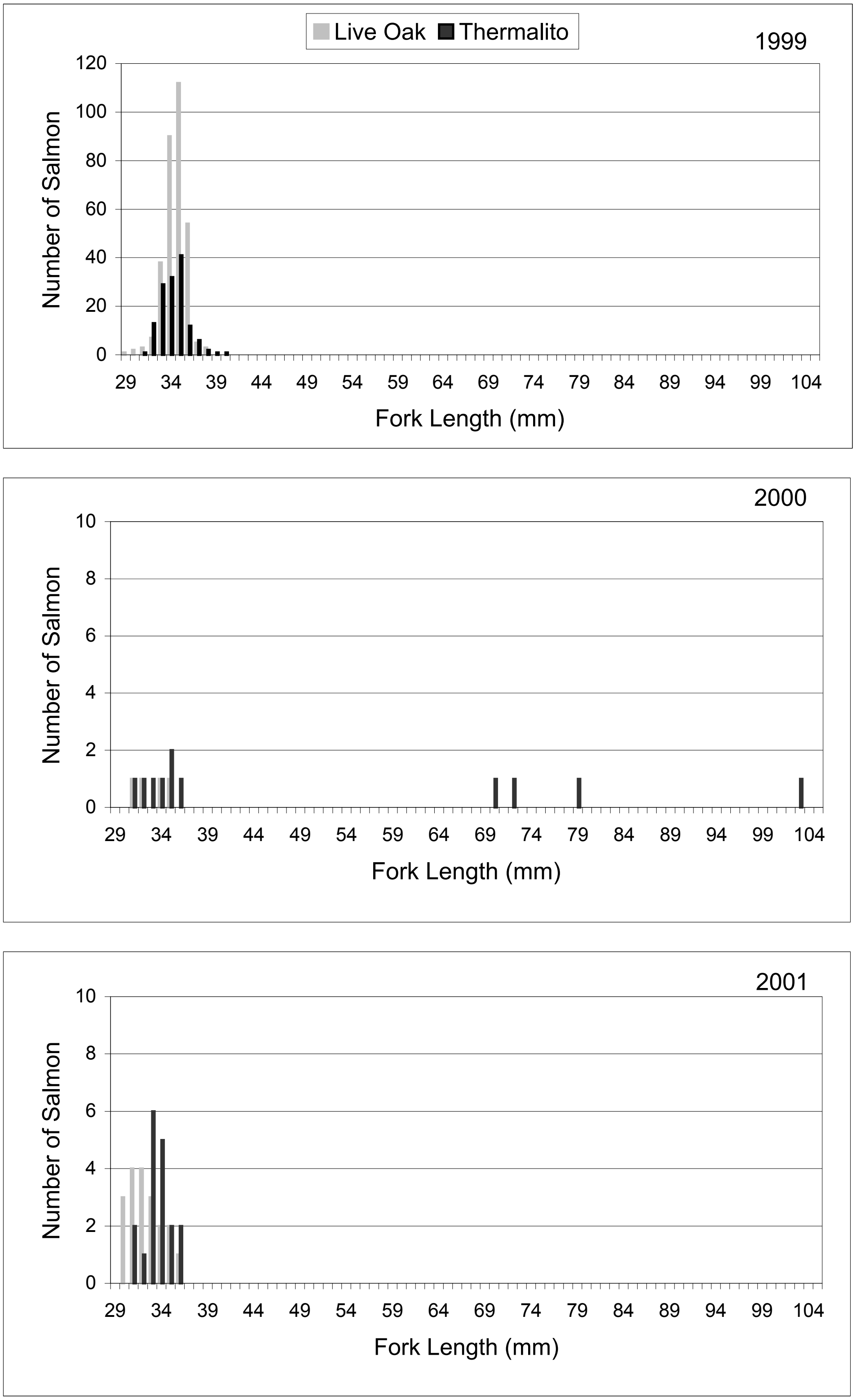
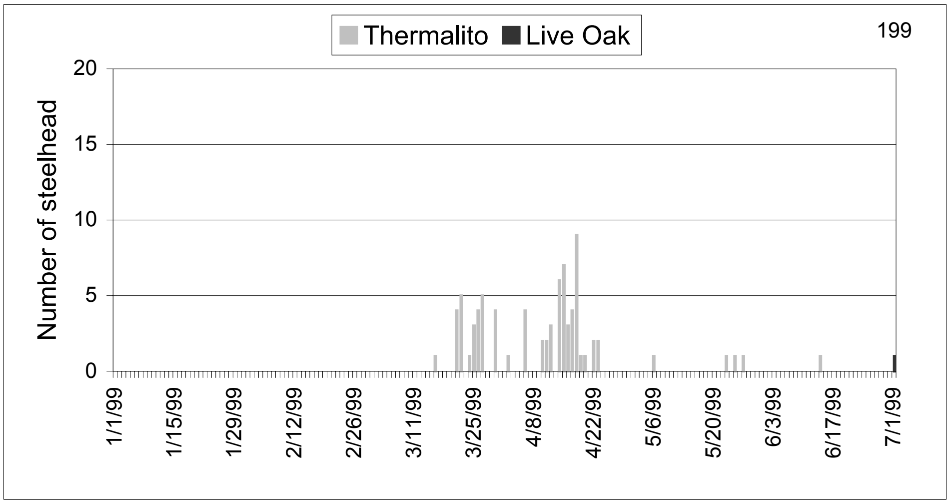
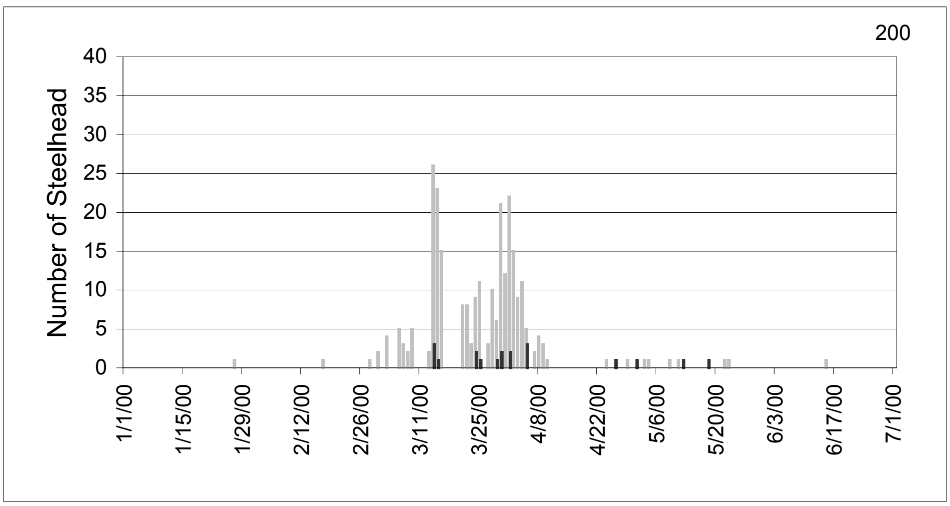


Figure 16. Length frequency distribution of late-fall size size chinook captured at Live Oak and Thermalito during all three years of trapping. Note the y-axis scale changes.





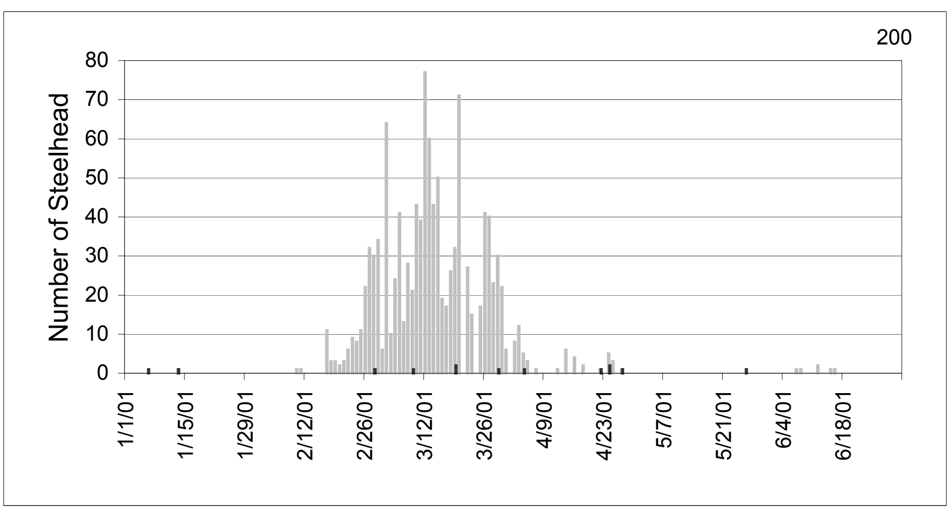


Figure 17. Daily catch distribution of juvenile steelhead caught at Thermalito and Live Oak during all three years of trapping. Note the y-axis scale changes.

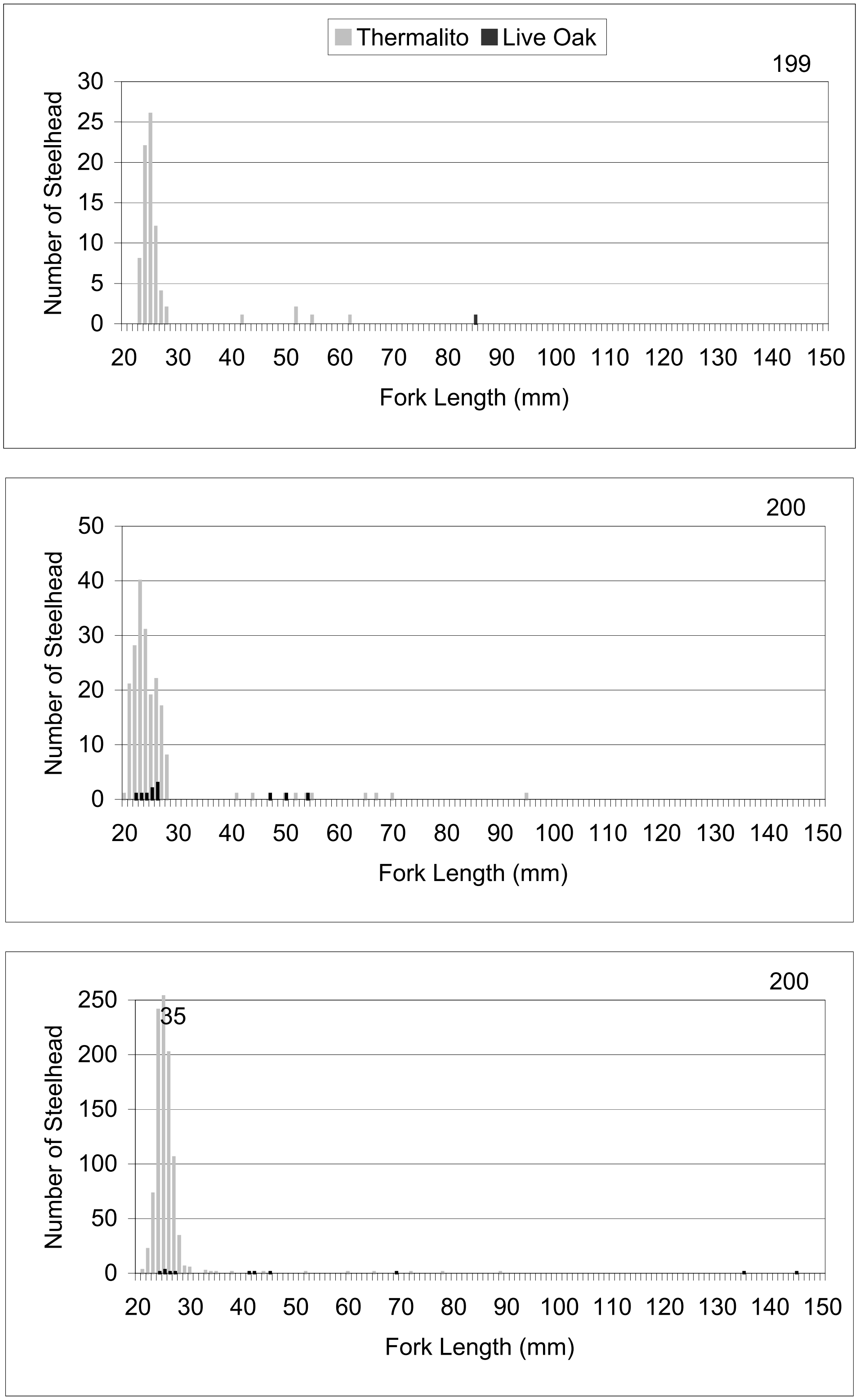


Figure 18. Length frequency distribution of juvenile steelhead captured at Thermalito and Live Oak during all three years of trapping. Note the y-axis scale changes.

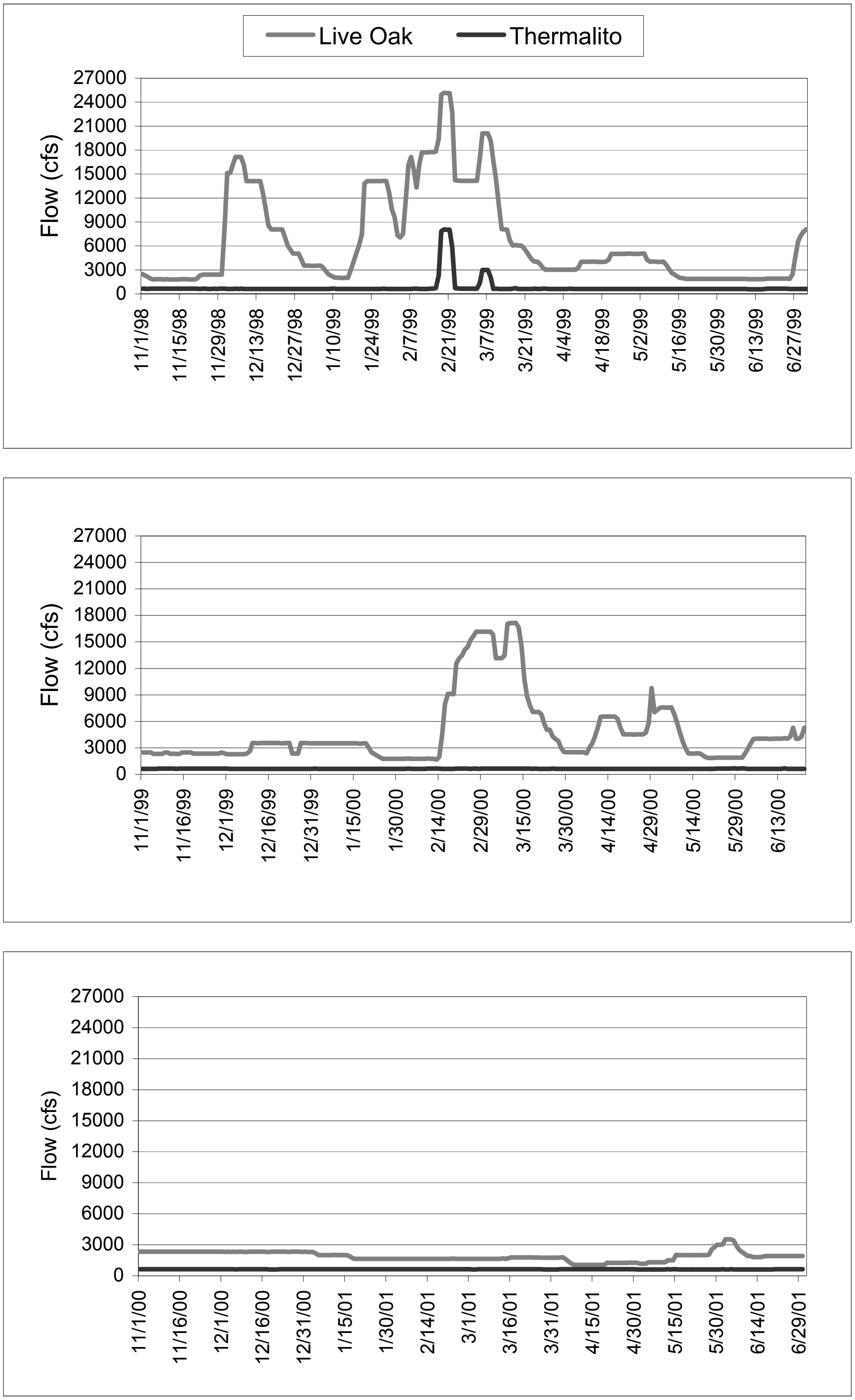


Figure 19. River flows at Live Oak and Thermalito during all threee years of trapping

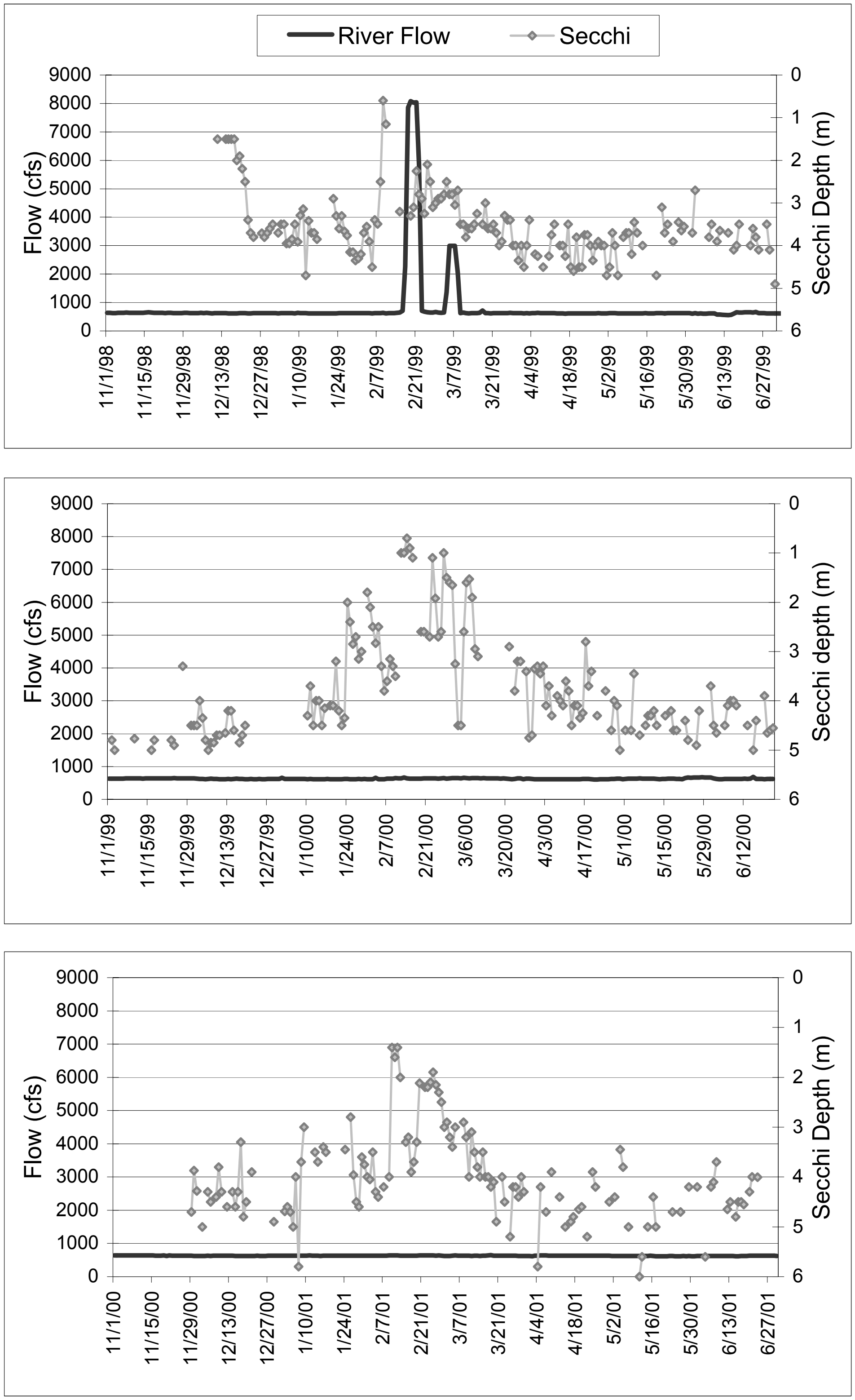


Figure 20. River flow and secchi depth at the Thermalito RST during all three years of trapping.

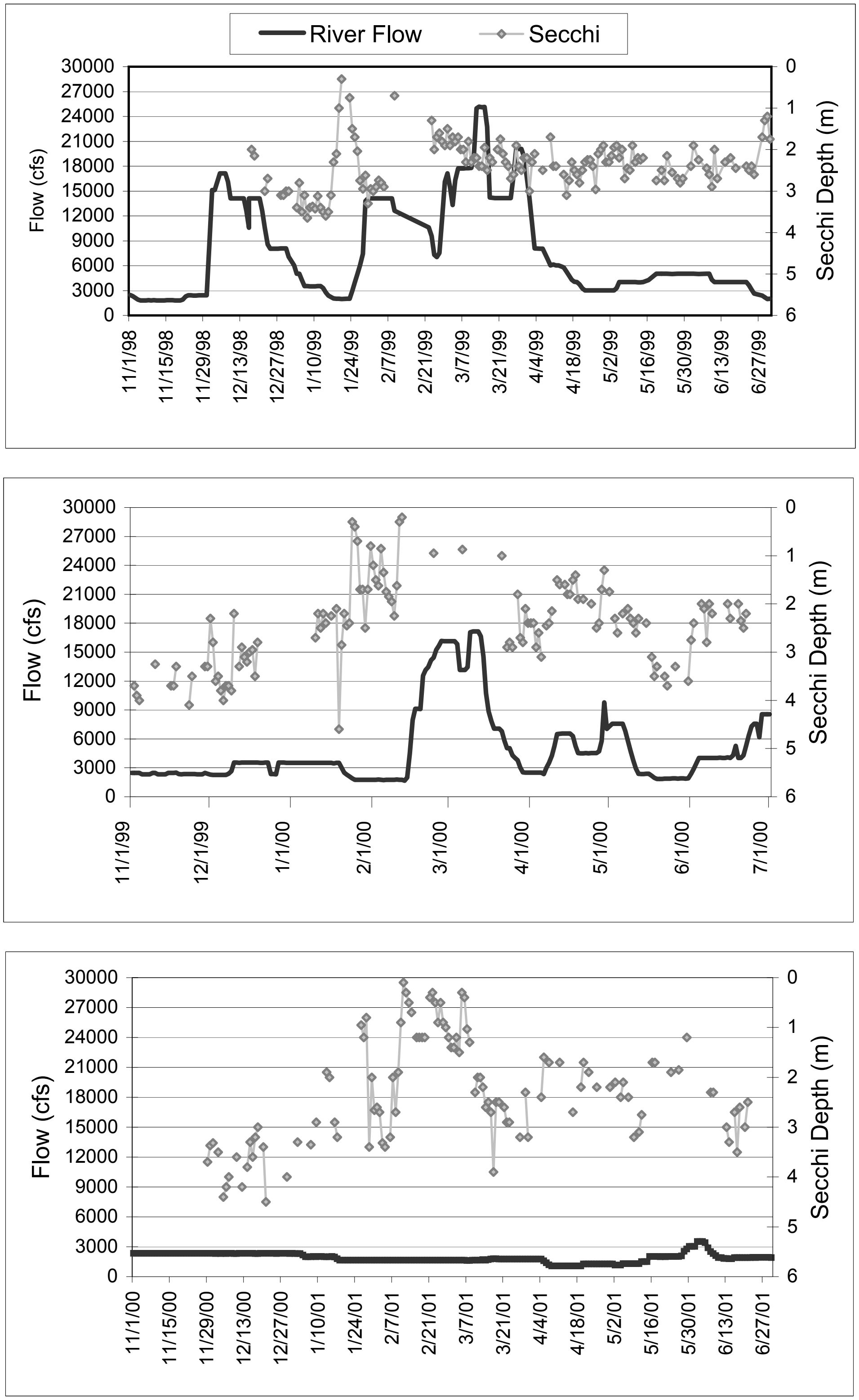


Figure 21. River flow and secchi depth at the Live Oak RST during all three years of trapping.

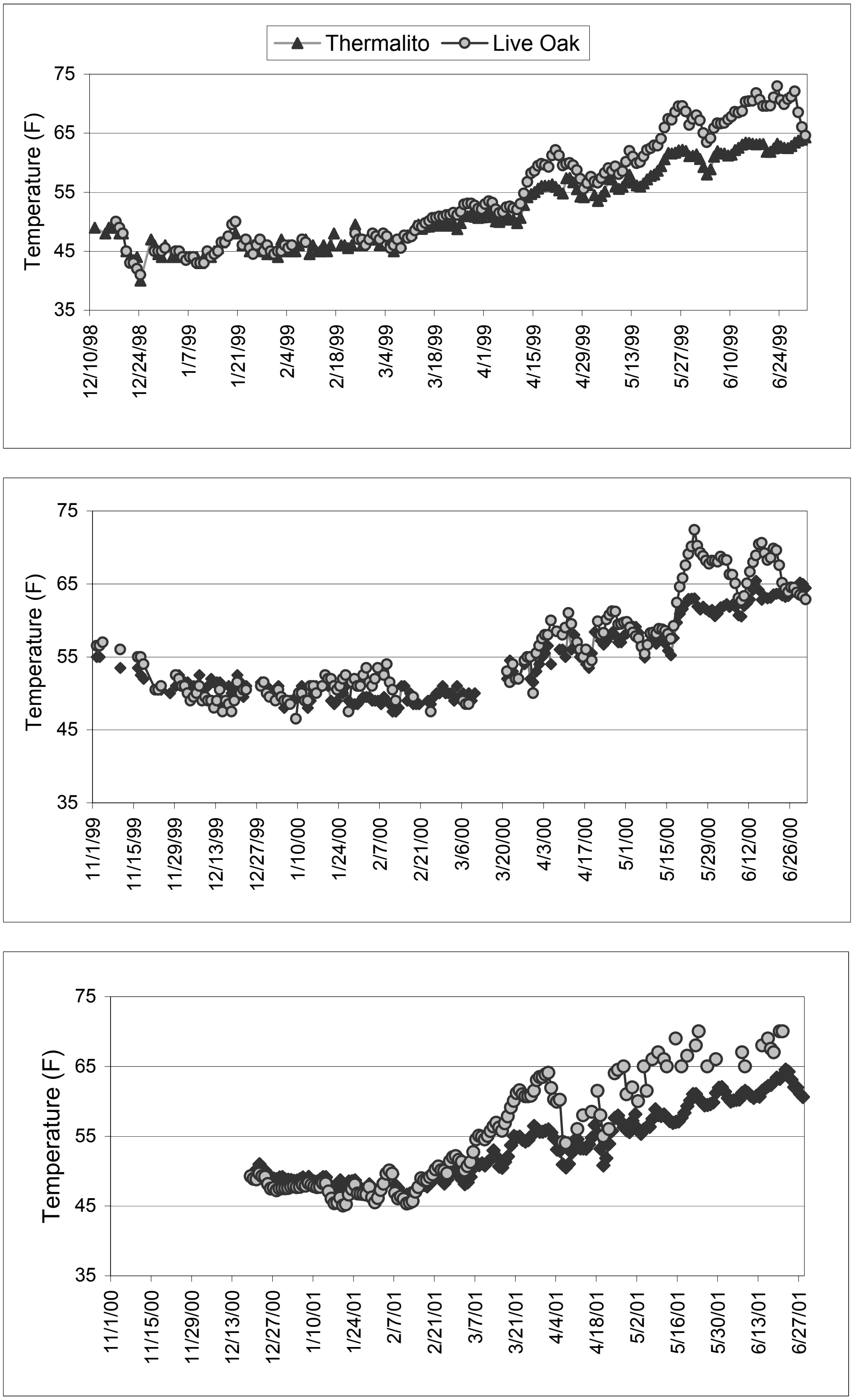


Figure 22. Average Daily water temperature at Live Oak and Themalito during all three years of trapping.

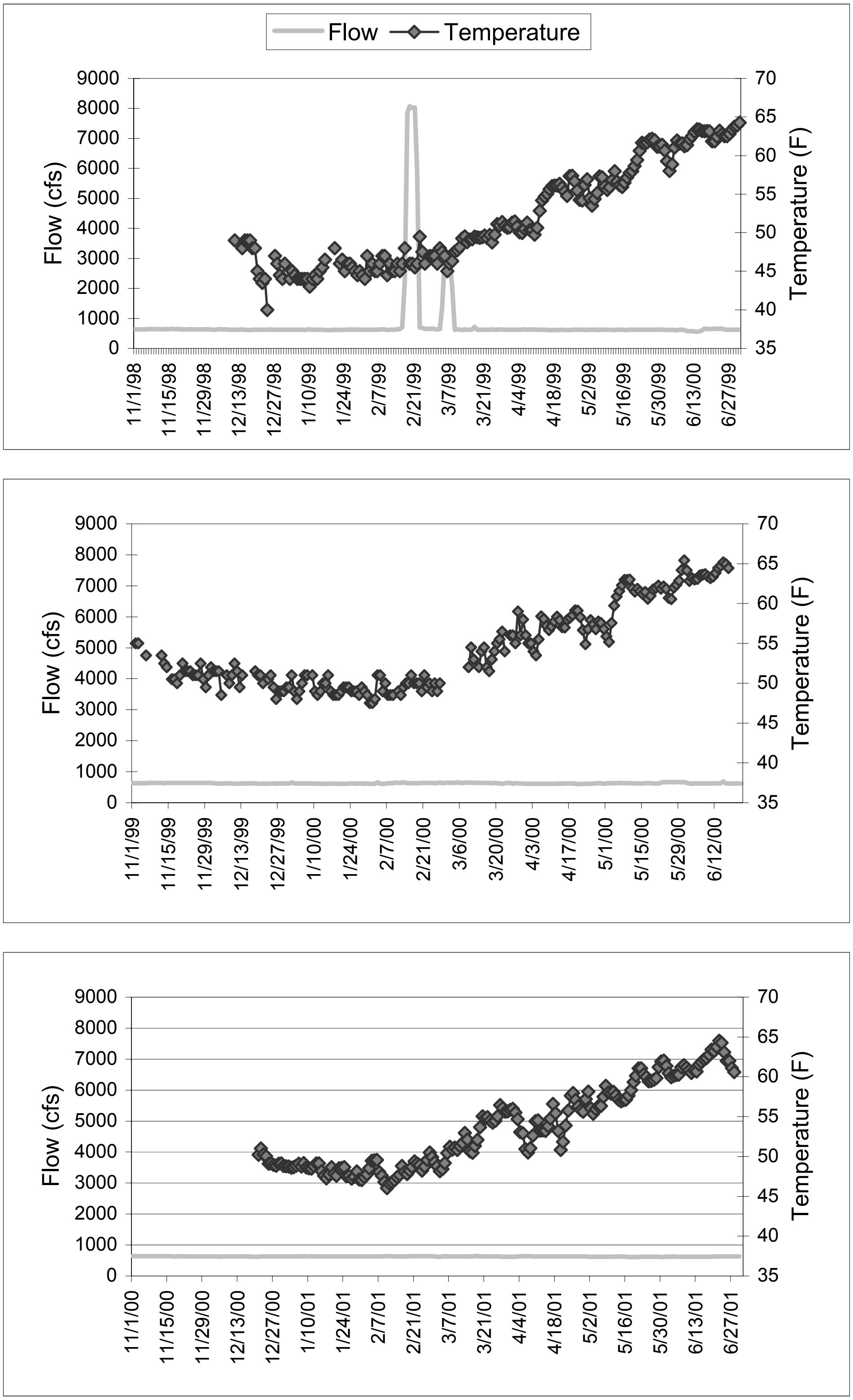


Figure 23. Daily flow and mean daily water temperature at the Thermalito screw trap during all three years of trapping.

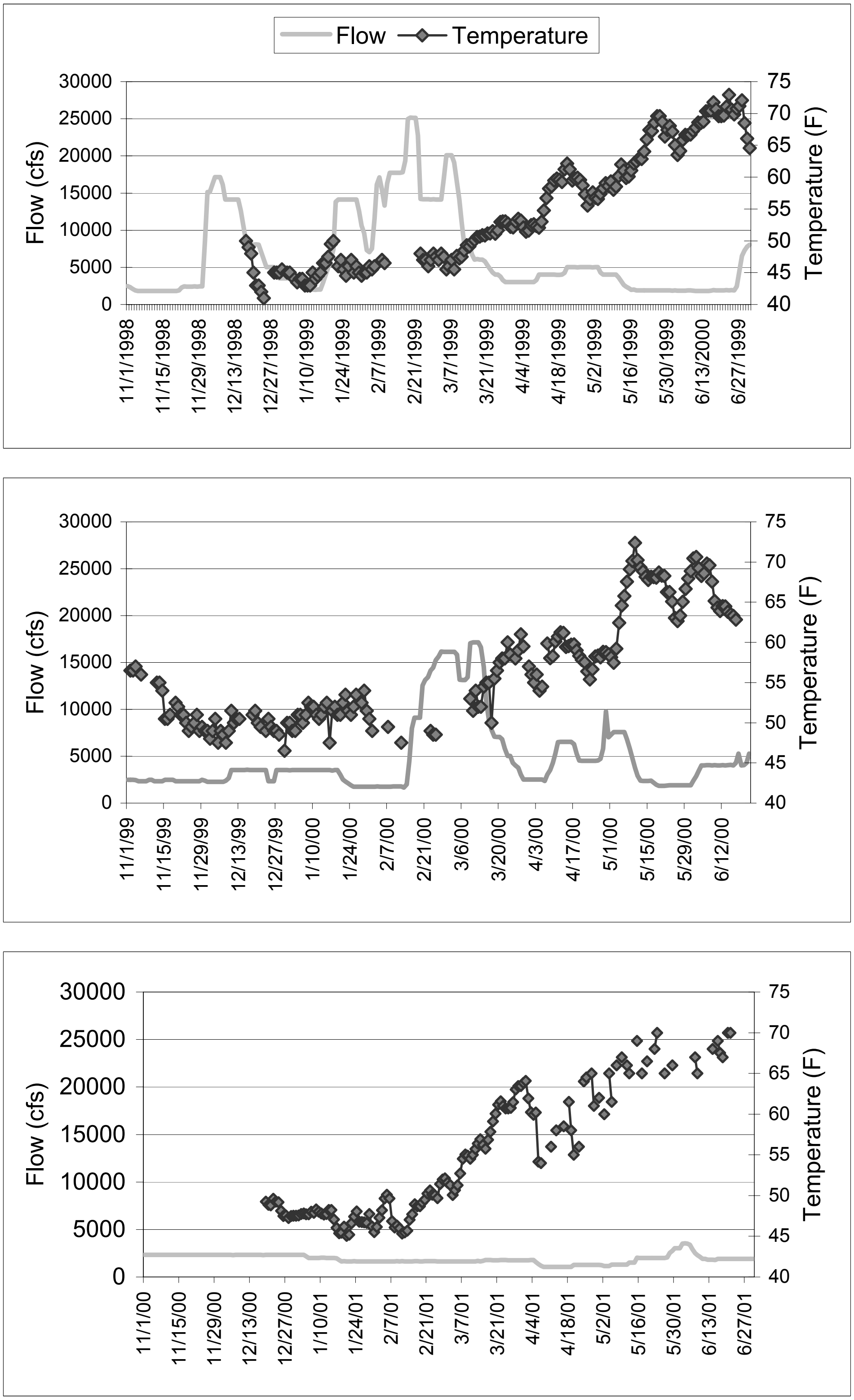
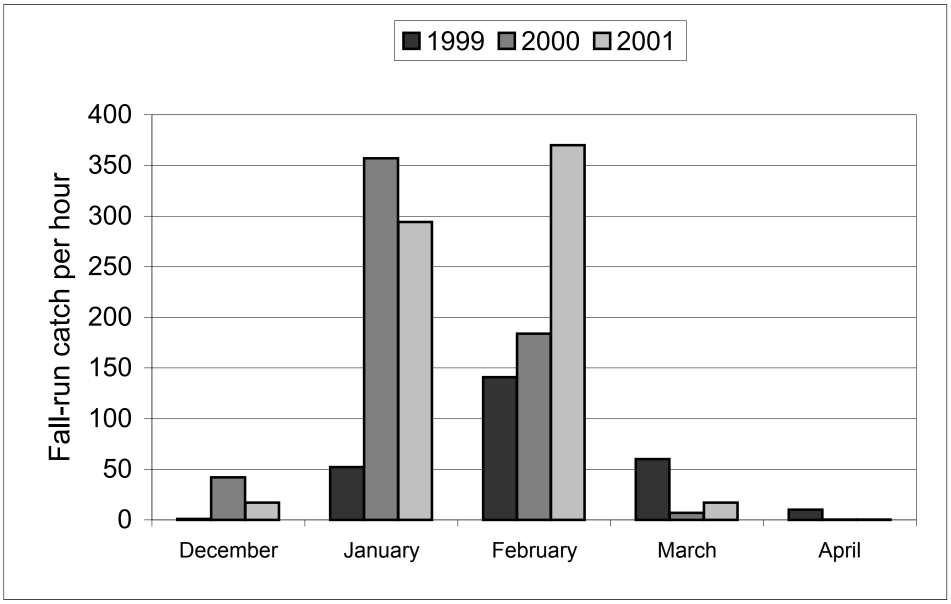


Figure 24. Daily flow and mean daily water temperature at the Live Oak screw trap during all three years of trapping.



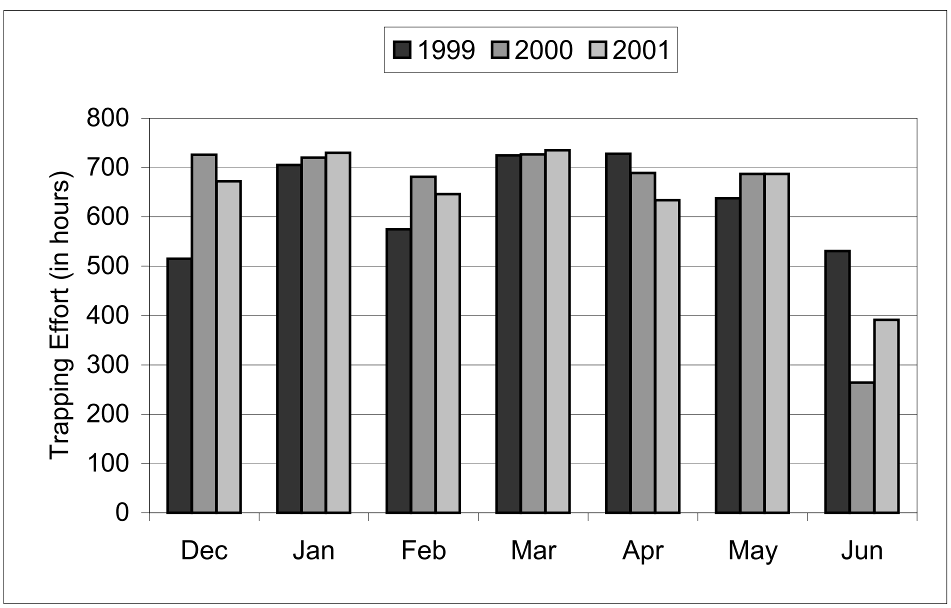
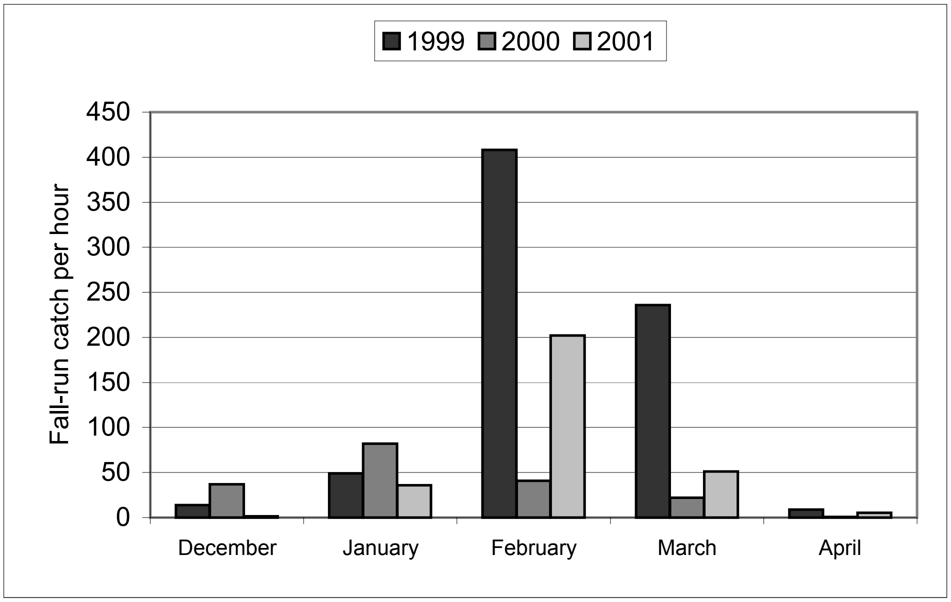


Figure 25 . Fall-run size catch per hour and trapping effort at the Thermalito screw trap during all three years of trapping.



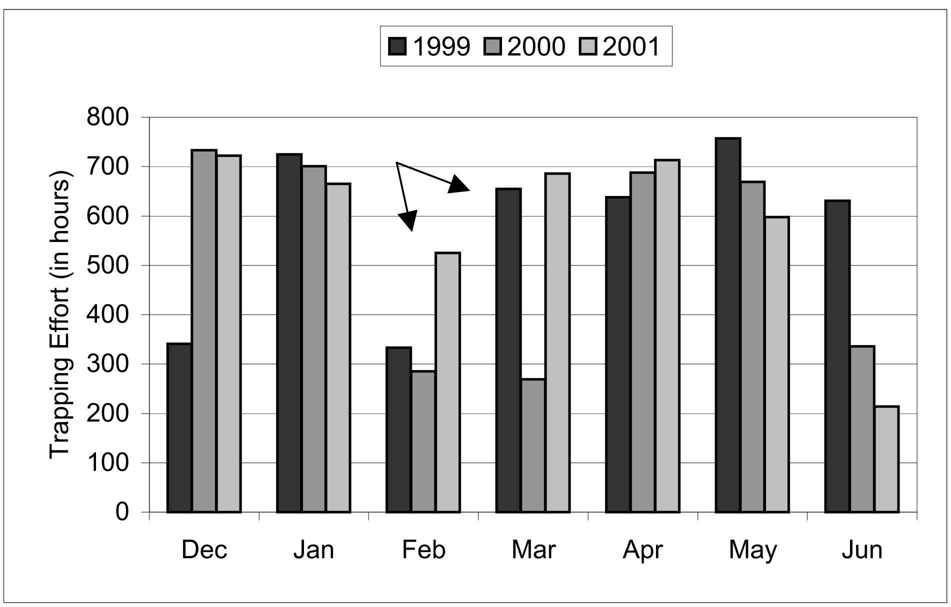


Figure 26. Fall-run size catch per hour and trapping effort at the Live Oak screw trap during all three years of trapping.

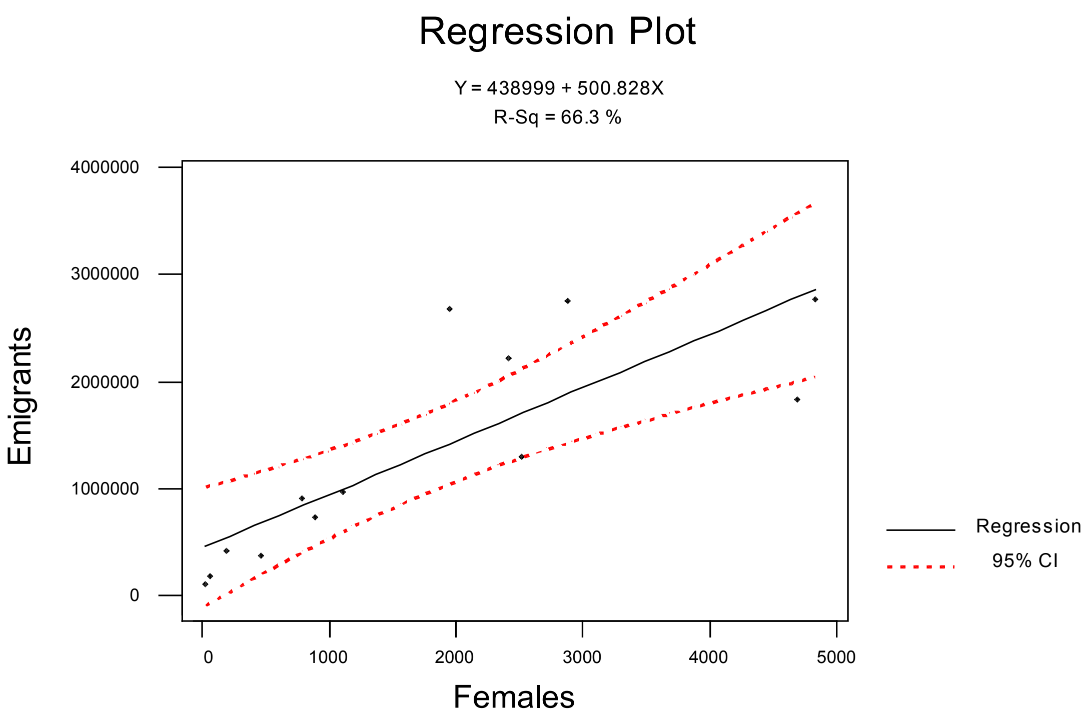


Figure 27. Linear regression model of the relationship between the number of spent females and the number of juvenile fall-run salmon emigrants in the LFC.

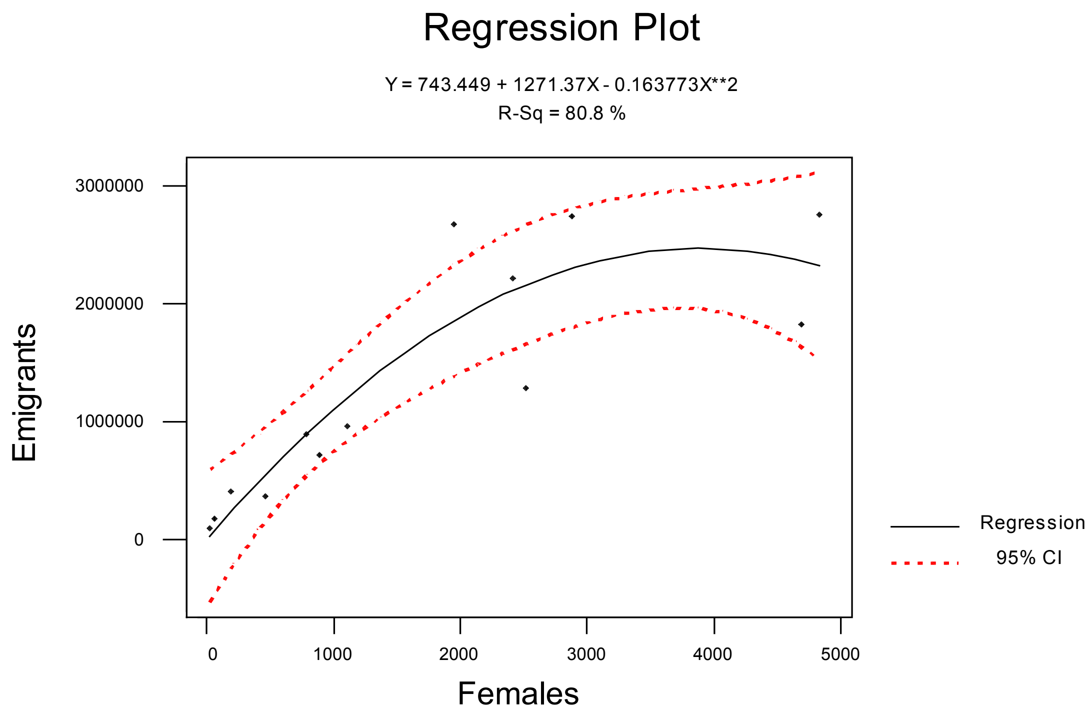


Figure 28. Quadratic regression model of the relationship between the number of spent females and the number of juvenile fall-run salmon emigrants in the LFC.

Table 1. Summary of non-chinook fishes caught by both Rotary Screw Traps during the 1999 trapping period.

Common Name	Scientific Name	Origin (*N/I)	Live Oak	Thermalito	Total
American Shad	*Alosa sapidissima*	I	15	0	15
Black Crappie	*Pomoxis nigromaculatus*	I	2	0	2
Bluegill	*Lepomis macrochirus*	I	76	7	83
Brook Trout	*Salvelinus fontinalis*	I	1	0	1
Brown Bullhead	*Ameiurus nebulosus*	I	1	0	1
Common Carp	*Cyprinus carpio*	I	1	0	1
Golden Shiner	*Notemigonus crysoleucas*	I	33	2	35
Green Sunfish	*Lepomis cyanellus*	I	1	0	1
Hardhead	*Mylopharadon conocephalus*	N	62	2	64
Hitch	*Lavinia exilicauda*	N	2	0	2
Largemouth Bass	*Micropterus salmoides*	I	137	59	196
Pacific Lamprey	*Lampetra tridentata*	N	235	135	370
Prickly Sculpin	*Cottus asper*	N	12	268	280
Redear Sunfish	*Lepomis microlophus*	I	7	1	8
Riffle Sculpin	*Cottus gulosus*	N	2	31	33
River Lamprey	*Lampetra ayresi*	N	3	0	3
Sacramento Squawfish	*Ptychocheilus grandis*	N	153	22	175
Sacramento Sucker	*Catostomus occidentalis*	N	1064	94	1158
Smallmouth Bass	*Micropterus dolomieu*	I	1	0	1
Speckled Dace	*Rhinichthys osculus*	N	6	0	6
Splittail	*Pogonichthys macrolepidotus*	N	0	0	0
Steelhead	*Oncorhynchus mykiss mykiss*	N	1	82	83
Tule Perch	*Hysterocarpus traski*	N	13	1	14
Wakasagi	*Hypomesus nipponensis*	I	512	12	524
Warmouth	*Lepomis gulosus*	I	10	5	15
Western Mosquitofish	*Gambusia affinis*	I	19	6	25
Unidentified fishes					
Bass	*Micropterus sp.*	I	61	62	123
Lamprey	*Lampetra sp.*	N	378	114	492
Sculpin	*Cottus sp.*	N	28	382	410
Sunfish	*Lepomis and Pomoxis sp.*	I	19	1	20
			2855	1286	4141

*N = Native, I = Introduced

Table 2. Summary of non-chinook fishes caught by both Rotary Screw Traps during the 2000 trapping period.

Common Name	Scientific Name	Origin (*N/I)	Live Oak	Thermalito	Total
American Shad	*Alosa sapidissima*	I	2	0	2
Black Crappie	*Pomoxis nigromaculatus*	I	4	0	4
Bluegill	*Lepomis macrochirus*	I	29	4	33
Brook Trout	*Salvelinus fontinalis*	I	0	0	0
Brown Bullhead	*Ameiurus nebulosus*	I	1	0	1
Common Carp	*Cyprinus carpio*	I	0	0	0
Golden Shiner	*Notemigonus crysoleucas*	I	17	1	18
Green Sunfish	*Lepomis cyanellus*	I	0	0	0
Hardhead	*Mylopharadon conocephalus*	N	158	4	162
Hitch	*Lavinia exilicauda*	N	4	0	4
Largemouth Bass	*Micropterus salmoides*	I	23	9	32
Pacific Lamprey	*Lampetra tridentata*	N	142	827	969
Prickly Sculpin	*Cottus asper*	N	22	0	22
Redear Sunfish	*Lepomis microlophus*	I	4	0	4
Riffle Sculpin	*Cottus gulosus*	N	3	76	79
River Lamprey	*Lampetra ayresi*	N	17	0	17
Sacramento Squawfish	*Ptychocheilus grandis*	N	174	14	188
Sacramento Sucker	*Catostomus occidentalis*	N	132	39	171
Smallmouth Bass	*Micropterus dolomieu*	I	1	0	1
Speckled Dace	*Rhinichthys osculus*	N	2	0	2
Splittail	*Pogonichthys macrolepidotus*	N	12	0	12
Steelhead	*Oncorhynchus mykiss mykiss*	N	21	263	284
Tule Perch	*Hysterocarpus traski*	N	50	0	50
Wakasagi	*Hypomesus nipponensis*	I	160	0	160
Warmouth	*Lepomis gulosus*	I	11	2	13
Western Mosquitofish	*Gambusia affinis*	I	21	12	33
Unidentified fishes					
Bass	*Micropterus sp.*	I	48	22	70
Lamprey	*Lampetra sp.*	N	253	178	431
Sculpin	*Cottus sp.*	N	3	0	3
Sunfish	*Lepomis and Pomoxis sp.*	I	9	0	9
			1323	1451	2774

*N = Native, I = Introduced

Table 3. Summary of non-chinook fishes caught by both Rotary Screw Traps during the 2001 trapping period.

Common Name	Scientific Name	Origin (*N/I)	Live Oak	Thermalito	Total
American Shad	*Alosa sapidissima*	I	8	0	8
Black Crappie	*Pomoxis nigromaculatus*	I	1	0	1
Bluegill	*Lepomis macrochirus*	I	9	1	10
Brook Trout	*Salvelinus fontinalis*	I	0	0	0
Brown Bullhead	*Ameiurus nebulosus*	I	1	0	1
Common Carp	*Cyprinus carpio*	I	0	0	0
Golden Shiner	*Notemigonus crysoleucas*	I	18	0	18
Green Sunfish	*Lepomis cyanellus*	I	11	0	11
Hardhead	*Mylopharadon conocephalus*	N	77	5	82
Hitch	*Lavinia exilicauda*	N	0	0	0
Largemouth Bass	*Micropterus salmoides*	I	27	21	48
Pacific Lamprey	*Lampetra tridentata*	N	715	77	792
Prickly Sculpin	*Cottus asper*	N	17	0	17
Redear Sunfish	*Lepomis microlophus*	I	4	0	4
Riffle Sculpin	*Cottus gulosus*	N	2	36	38
River Lamprey	*Lampetra ayresi*	N	67	4	71
Sacramento Squawfish	*Ptychocheilus grandis*	N	44	7	51
Sacramento Sucker	*Catostomus occidentalis*	N	23	1	24
Smallmouth Bass	*Micropterus dolomieu*	I	1	0	1
Speckled Dace	*Rhinichthys osculus*	N	0	0	0
Splittail	*Pogonichthys macrolepidotus*	N	2	0	2
Steelhead	*Oncorhynchus mykiss mykiss*	N	14	1143	1157
Tule Perch	*Hysterocarpus traski*	N	22	2	24
Wakasagi	*Hypomesus nipponensis*	I	185	548	733
Warmouth	*Lepomis gulosus*	I	13	2	15
Western Mosquitofish	*Gambusia affinis*	I	16	2	18
Unidentified fishes					
Bass	*Micropterus sp.*	I	0	0	0
Lamprey	*Lampetra sp.*	N	114	134	248
Sculpin	*Cottus sp.*	N	1	0	1
Sunfish	*Lepomis and Pomoxis sp.*	I	12	0	12
			1404	1983	3387

*N = Native, I = Introduced

Table 4. Monthly summary of all chinook salmon captured at both rotary screw traps during the 1999, 2000 and 2001 trapping periods. Totals are not adjusted for un-sampled days.

Live Oak	1998		1999						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Fall Chinook	---	3508	31631	116956	158470	4519	2523	30	317637
Spring Chinook	---	23	5	3	2	25	3	---	61
Late Fall Chinook	---	---	---	---	---	357	3	---	360

Thermalito	1998		1999						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Fall Chinook	---	469	31791	79065	42715	1587	106	26	155759
Spring Chinook	---	18	---	---	---	---	---	---	18
Late Fall Chinook	---	---	---	---	---	162	7	---	169

Live Oak	1999		2000						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Fall Chinook	---	16327	57705	19111	4237	714	147	6	98247
Spring Chinook	13	2311	76	1	---	---	---	---	2401
Late Fall Chinook	---	---	---	---	---	3	1	---	4

Thermalito	1999		2000						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Fall Chinook	---	22435	246909	113440	3161	177	30	8	386160
Spring Chinook	51	3458	177	49	5	12	1	---	3753
Late Fall Chinook	1	---	---	---	---	7	1	---	9

Live Oak	2000		2001						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Fall Chinook	---	716	27228	134970	38655	4467	1408	1	207445
Spring Chinook	2	66	---	4	---	10	6	---	88
Late Fall Chinook	---	---	---	---	---	38	---	---	38

Thermalito	2000		2001						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Fall Chinook	---	5171	220110	235478	12364	159	18	29	473329
Spring Chinook	7	151	0	15	4	2	---	---	179
Late Fall Chinook	---	---	---	---	---	29	3	---	32

Table 5. Trap efficiency data for 1999-2001

1999

	Mark Type	Release Date	Recovery Period	# marked	# recaptured	Efficiency %
Live Oak	Adipose clip	2/25/99	02/25-02/28	3151	15	0.48
Live Oak	Bismarck	3/19/99	03/19-03/22	999	65	6.50
Live Oak	Bismarck	3/23/99	03/23-03/26	999	36	3.60
Thermalito	Adipose clip	2/4/99	02/04-02/07	3181	22	0.69
Thermalito	Adipose clip	2/16/99	02/16-02/17	1091	5	0.46
Thermalito	Bismarck	3/16/99	03/16-03/19	990	23	2.30

2000

	Mark	Release Date	Recovery Period	# marked	# recaptured	Efficiency %
Live Oak	Bismarck	12/21/99	12/21-12/23	999	36	3.60
Live Oak	Bismarck	1/5/00	01/05-01/08	990	17	1.70
Live Oak	Bismarck	1/11/00	01/11-01/14	1167	24	2.06
Live Oak	Bismarck	1/18/00	01/18-01/21	959	37	3.86
Live Oak	Bismarck	1/31/00	01/31-02/03	1093	14	1.28
Live Oak	Bismarck	2/7/00	02/07/-02/10	930	4	0.43
Thermalito	Bismarck	12/31/99	12/31-01/03	1000	41	4.10
Thermalito	Bismarck	1/4/00	01/04-01/07	1000	46	4.60
Thermalito	Bismarck	1/11/00	01/11-01/14	1123	41	3.65
Thermalito	Bismarck	1/18/00	01/18-01/21	895	24	2.68
Thermalito	Bismarck	1/24/00	01/24-01/27	1025	38	3.71
Thermalito	Bismarck	1/31/00	01/31-02/03	940	26	2.77
Thermalito	Bismarck	2/7/00	02/07-02/10	978	23	2.35

2001

	Mark	Release Date	Recovery Period	# marked	# recaptured	Efficiency %
Live Oak	Bismarck	1/17/01	01/17-01/21	996	1	0.10
Live Oak	Bismarck	1/25/01	01/25-01/29	390	4	1.03
Live Oak	BB/Flo Blue	2/6/01	02/06-02/13	400	7	1.75
Live Oak	BB/Flo Red	2/14/01	02/14-02/19	593	16	2.70
Live Oak	BB/Flo Blue	2/21/01	02/21-02/25	500	6	1.20
Live Oak	Bismarck	3/5/01	03/05-03-11	1000	0	0.00
Live Oak	Bismarck	3/12/01	03/12-03/18	998	4	0.40
Live Oak	Bismarck	3/19/01	03/19-03/22	305	0	0.00
Thermalito	Bismarck	1/8/01	01/08-01/12	549	19	3.46
Thermalito	Bismarck	1/24/01	01/24-01/29	470	8	1.70
Thermalito	BB/Flo Red	2/5/01	02/05-02/14	485	19	3.92
Thermalito	BB/Flo Blue	2/15/01	02/15-02/19	863	35	4.06
Thermalito	BB/Flo Red	2/20/01	02/20-02/25	340	12	3.53
Thermalito	Bismarck	2/26/01	02/26-03/04	2980	71	2.38
Thermalito	Bismarck	3/5/01	03/05-03/11	500	5	1.00
Thermalito	Bismarck	3/12/01	03/12-03/18	498	6	1.20

Table 6. Emigration estimates for 1999, 2000 and 2001.

Low Flow Channel

	1999	2000	2001
Fall Chinook	7,097,687	12,486,570	16,766,478
Spring Chinook	1006	78,587	7502

High Flow Channel

	1999	2000	2001
Fall Chinook	20,527,852	*5,271,548	29,005,361
Spring Chinook	3796	*69,523	15,238

*The Live Oak trap did not fish for 19 days in Feb and Mar of 2000 due to high flows

Table 7. Coded wire tag releases of naturally spawned juvenile chinook salmon over the past four years of trapping.

Year	Dates of Tagging	Total Released
1998	01/25/1998-03/22/1998	63,989
1999	01/17/1999-03/26/1999	136,470
2000	01/03/2000-02/19/2000	147,156
2001	01/05/2001-03/09/2001	213,961

Table 8. Regression analysis of river flow (cfs) as a predictor of chinook catch at Live Oak and Thermalito 1999-2001.

Live Oak

Year	r^2	p-value
1999	0.039	0.075
2000	0.029	0.096
2001	0.111	0.001

Thermalito

Year	r^2	p-value
1999	0.017	0.246
2000	0.022	0.118
2001	0.033	0.063

Table 9. Secchi depth values recorded at Thermalito and Live Oak 1999-2001.

Live Oak

Year	Mean Depth (m)	Standard Deviation	High	Low	Range
1999	2.4	0.9	4.6	0.2	4.4
2000	2.4	0.6	3.7	0.3	3.4
2001	2.4	1.1	4.5	0.1	4.4

Thermalito

Year	Mean Depth (m)	Standard Deviation	High	Low	Range
1999	3.5	0.7	4.9	0.6	4.3
2000	3.7	1.1	5.0	0.7	4.3
2001	4.0	0.9	6.1	1.4	4.7

Table 10. Regression analysis of water clarity as a predictor of chinook catch at Live Oak and Thermalito 1999-2001.

Live Oak

Year	r^2	p-value
1999	0.003	0.622
2000	0.117	0.004
2001	0.221	0.000

Thermalito

Year	r^2	p-value
1999	0.000	0.855
2000	0.055	0.023
2001	0.146	0.000